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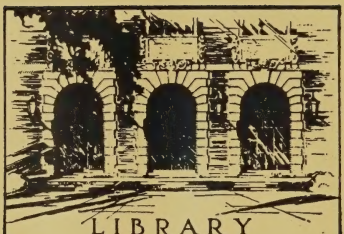

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Use and Abuse of the Steam-Boiler.

OPINIONS OF THE PRESS.

The Iron Age, N. Y.

This work is intended to be a hand-book for the fireman, purchaser, and user of boilers, rather than for the boiler-maker or scientific man. The work is somewhat smaller than the other hand-books by the same author. It is, however, bound in uniform style with them. Most of the common forms of boilers are illustrated, as well as many of those not usually seen. The author aims, he tells us, at a dissemination of plain, practical, and correct information in regard to the functions of the steam-boiler, its care and management. The work, as a whole, is valuable, presenting in a compact form many of the tables, facts, and figures which have heretofore been scattered among a wide range of authorities.

Engineering News, Chicago, Ill.

Mr. Roper is the author of several well-known hand-books relating to the steam-engine, and steam machinery in general. In this, his latest work, he states that his object is "simply to show what the results of his thirty years' personal experience with all classes of boilers prove to be the safest and most durable materials for their manufacture, to show the absolute necessity of good workmanship in their construction, and to call the attention of owners, engineers, and firemen to the rules that limit their usefulness, safety, and longevity." As in all his other hand-books, the writer addresses himself to men of ordinary intelligence,—those found in charge of steam-engines and boilers,—and in consequence his book is written in the plainest and most intelligible language that can be chosen. We have not the time, nor possibly the necessary amount of practical knowledge of all the latest improvements in steam-boilers, to criticise closely and intelligently the contents of the book, but in connection with it we would call attention to the large number

of boiler explosions, attended with great loss of life, that have recently occurred in this country and in England, and which, upon investigation, have been proven to be the results of ignorance and carelessness on the part of attendants, and we cannot but think that steam-users would find it greatly to their advantage if such plain handy-books as those of Mr. Roper's were placed in the hands of every attendant upon a steam-boiler or engine, and his attention called to the advantage of making himself familiar with its contents.

The Locomotive, Hartford, Conn.

"USE AND ABUSE OF THE STEAM-BOILER."—Stephen Roper, of Philadelphia, is the author of several hand-books on Steam-Engineering, which we have noticed in the LOCOMOTIVE, from time to time, as they have been issued. Their great merit is, that they are adapted to the wants of those whose circumstances had prevented them from obtaining such an education as will enable them to cope with the various formulæ that enter into the higher branches of steam-engineering. Most works on steam shoot over the heads of this class of people. And yet, when we come to the matter of actually handling a boiler, or an engine in use, their practical experience is invaluable.

We have said thus much by way of introducing a new work which Mr. Roper has just issued, viz., USE AND ABUSE OF THE STEAM-BOILER. This contains just the kind of information that a person having the care of steam-boilers needs, and such information as we have put forth in our various publications from time to time. We heartily recommend it to all persons who have to do with steam-boilers, whether as proprietors or engineers. The hand-books which Mr. Roper has issued are as follows: "Catechism of Steam-Engines," "Hand-Book of the Locomotive," "Hand-Book of Modern Steam Fire-Engines," "Hand-Book of Land and Marine Engines," "Use and Abuse of the Steam-Boiler."

Mr. Roper's address is 447 North Broad Street, Philadelphia, and those having the care of steam-boilers cannot do better than address him on the subject.

The Newark Artisan, Newark, N. J.

We have, from time to time, favorably noticed the publications, relating to the steam-engine proper and its collaterals, by Stephen Roper, 447 North Broad Street, Philadelphia, Pa., and published by Messrs. Claxton, Remsen & Haffelfinger of that city. The recent publication, USE AND ABUSE OF THE STEAM-BOILER, meets our most hearty approval, as embodying fully all its title indicates. The work is entirely devoid of abstruse terms, and comes squarely down to the understanding of the ordinarily educated mechanic in so plain a manner as cannot be misunderstood. As we have said of Mr. Roper's previous publications, we now say of this,—that employers can do themselves no greater service than placing a copy of this work in the hands of the employé in charge of their engines.

North-western Lumberman, Chicago, Ill.

As the author of "Roper's Hand-Book of the Locomotive," "Roper's Hand-Book of Land and Marine Engines," "Roper's Catechism of High Pressure or Non-Condensing Steam-Engines," and of other valuable contributions to our mechanical literature, Mr. Roper needs no introduction to such of our readers as are interested in steam machinery. Like his former works, the USE AND ABUSE OF THE STEAM-BOILER is eminently practical in its character and designed for the use of practical men. Bearing in mind the difficulty which ordinary mechanics experience in endeavoring, as they sometimes do, to extract information from books of a scientific nature, he has used plain, clear language, to convey his meaning instead of ambiguous scientific terms, and where it has been necessary to give mathematical information, has employed simple arithmetical calculations, in lieu of abstruse algebraic formulæ. From an experience with boilers and steam machinery extending over a period of thirty years, Mr. Roper has been able to gather an amount of practical knowledge which, combined with that derived from other sources and condensed and arranged

in the convenient form in which we find it, makes one of the most valuable books for reference and instruction, in this particular department, to be found in the language. It is wide in its scope, and includes besides a full description and explanation of nearly all the different styles of boilers which the genius of the nineteenth century inventor has produced, how best to use and preserve them and their attachments; a large quantity of additional matter in the way of rules for estimating the strength of materials, safe working pressure, horse-power and heating surface of steam-boilers, etc., etc. The tables, which are plentifully interspersed throughout the work — and which are fortunately arranged so as to be comprehensible even to those who are not Ph. D.'s — also contain within a small space a vast amount of information which is of practical value to the every-day engineer. It is printed in large, clear type, and bound in morocco, in handy, pocket-book form, and is in all respects a volume which every one interested in steam will be the richer and wiser for having in his possession.

National Carbuilder, New York City.

This is a very compact and comprehensive pocket manual, and is the only book that has been published in this country devoted exclusively to this subject. The various kinds of steam-boilers now in use, comprising stationary, locomotive, fire and marine, are illustrated and described. Rules are given for estimating strength of materials, safe working pressure, horse-power, heating surface, etc. Nothing is omitted pertaining to the functions, care, and management of boilers. The volume is a plain, practical treatise, devoid of scientific technicalities and algebraic formulas, and can be easily understood by the ordinary reader. It should be in the hands of every mechanic in charge of steam-boilers. There is a general and analytical index.

USE AND ABUSE

OF

THE STEAM-BOILER.

BY

STEPHEN ROPER, ENGINEER,

Author of

"Roper's Catechism of High-Pressure or Non-Condensing Steam-Engines," "Roper's Hand-Book of the Locomotive," "Roper's Hand-Book of Land and Marine Engines," "Roper's Hand-Book of Modern Steam Fire-Engines," "Roper's Handy-Book for Engineers," "Roper's Improvements in Steam-Engines", etc., etc.

With Illustrations.

ELEVENTH EDITION, REVISED.

PHILADELPHIA:

EDWARD MEEKS,

1012 WALNUT STREET.

1890.

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TO

JAMES M. ALLEN, Esq.,

PRESIDENT OF THE HARTFORD STEAM-BOILER INSPECTION AND INSURANCE COMPANY,

This Volume

IS

RESPECTFULLY INSCRIBED

BY

THE AUTHOR,

As a mark of appreciation of the eminent services which he has rendered humanity by his thorough investigations into the causes of steam-boiler explosions, by means of which they have been stripped of their apparent mystery and assigned to real causes.

INTRODUCTION.

IT is not the writer's intention to enter into an elaborate discussion on the relative merits of the different varieties of boilers now in use, nor on the open and unsettled questions connected with steam-boiler engineering, such as the horse-power of boilers, the quantity of grate and heating surface which should constitute the commercial horse-power, the proportion of safety-valves to grate and heating surface, or what part of the shell, flues, or tubes of a boiler should be considered heating surface. His object being simply to show what the results gathered from experience prove to be the safest and most durable materials for their manufacture, to show the absolute necessity of good workmanship in their construction, and to call the attention of owners, engineers, and firemen to the evils that limit their usefulness, safety, and longevity.

The writer's experience with all classes of boilers extends over a period of thirty years, which enables him to fully understand the kind of information most needed by the men generally found in charge

of them, and he has tried to convey his meaning in language so plain that it may be understood by any person of ordinary intellect. Of what use are algebraical formulæ to men who do not fully understand them? Do we not write and speak to make ourselves understood? If so, why should anything be embodied in a work on the care and management of steam-boilers which persons of the most limited education cannot comprehend? Until quite recently, it was impossible, for persons needing information, to procure a plain, practical treatise on this subject; this arose, perhaps, from the fact, that men who had attained proficiency in this line of business had no taste for devoting their time to writing, and that those whose circumstances enabled them to do so were prevented by a want of that practical knowledge which can only be obtained by years of hard work, close study and observation.

The great mistake of many writers on the steam-boiler and steam-engine is, that they write too much; if they would condense and render such explanations as would come within the comprehension of men of ordinary intelligence, they would do more to diffuse information among the class of men for whom they pretend to write than by writing elaborate treatises,

replete with algebraical formulæ and purely scientific terms, and couched in language incapable of being understood by the very men who most need the information, leaving them to interpret the meaning as best they may. What engineers and mechanics generally want is perspicuous and terse language, concise expressions and clear explanations.

It is also quite customary for writers on the steam-boiler to regale their readers with accounts of the able researches of Joule, Peclet, Rankine, and others, in the field of Thermo-dynamics, which, however edifying to the writers themselves, can be of no value to men having charge of steam-boilers, as not one in one thousand of them, even if they could procure these scientific theories, (which is extremely doubtful, as the researches of Joule and Peclet were never published in the English language,) would be able to decipher or understand them; and Rankine's works, though quite common, are nevertheless beyond the comprehension of the majority of men in charge of steam-boilers. There is far greater need for the dissemination of plain, practical, and correct information in regard to the functions of the steam-boiler, its care and management, than of the steam-engine, because the former is more subject to the uncertainties of

indiscretion and ignorance than the latter, and in the case of the former, neglect is attended with more serious results.

Rules are given for estimating the strength of materials, safe working pressure, horse-power and heating surface of steam-boilers, the collapsing pressure of flues, etc., and also the aggregate strain to which boiler shells and flues are subjected when in use, as a knowledge of the material so extensively employed in the construction of steam-boilers, and the strains to which they are subjected, must be of great value to engineers, whether engaged in the construction of new or in the repairing of old ones. In fact, it has been the main object of the writer, in the preparation of this book, to put in practical shape, for the benefit of engineers and steam-users, the information collected from his own experience, as well as from other reliable sources; and while, in the preparation of the book, it became necessary to discuss the relative merits and peculiarities of a great variety of steam-generators, the writer has endeavored to do so without prejudice, and solely with the view of benefiting the class of persons for whom the book was intended.

S. R.

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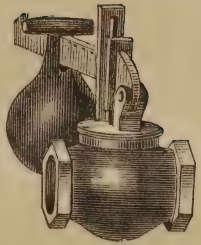
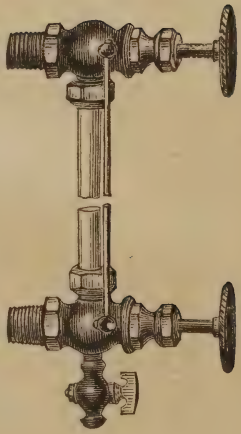
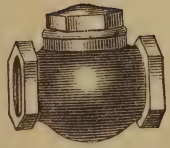
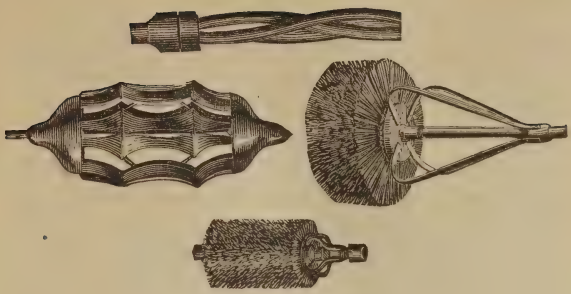






ADJUNCTS OF THE STEAM-BOILER.



USE AND ABUSE

OF

THE STEAM-BOILER.

STEAM-BOILERS.

A STEAM-BOILER may be defined as a close vessel, in which steam is generated. It may assume an endless variety of forms, and can be constructed of various materials.

Since the introduction of steam as a motive power, a great variety of boilers has been designed, tried, and abandoned; while many others, having little or no merit as steam-generators, have their advocates, and are still continued in use. Under such circum-

stances, it is not surprising that quite a variety of opinions are held on the subject. This difference of opinion relates not only to the form of boiler best adapted to supply the greatest quantity of steam with the least expenditure of fuel, but also to the dimensions or capacity suitable for an engine of a given number of horse-power; and while great improvements have been made in the manufacture of boiler materials within the past fifteen years, yet the number of inferior steam-boilers seems to increase rather than diminish. It would be difficult to assign any reasonable cause for this, except that, of late years, nearly the whole attention of theoretical and mechanical engineers has been directed to the improvement and perfection of the steam-engine, and practical engineers, following the example set by the leaders, devote their energies to the same object.

This is to be regretted, as the construction and application of the steam-boiler, like the steam-engine, is deserving of the most thorough and scientific study, as on the basis of its employment rest some of the most important interests of civilization. Until quite recently, the idea was very generally entertained that the purely mechanical skill required to enable a person to join together pieces of metal, and thereby form a steam-tight and water-tight vessel of given dimension, to be used for the generation of steam to work an engine, was all that was needed; experience has shown, however, that this is but a small portion

of the knowledge that should be possessed by persons who turn their attention to the design and construction of steam-boilers, as the knowledge wanted for this end is of a scientific as well as of a mechanical nature.

As the boiler is the source of power, and the place where the power to be applied is first generated, and also the source from which the most dangerous consequences may arise from neglect or ignorance, it should attract the special attention of the designing and mechanical engineer, as it is well known that from the hour it is set to work, it is acted upon by destroying forces, more or less uncontrollable in their work of destruction. These forces may be distinguished as chemical and mechanical. In most cases they operate independently, though they are frequently found acting conjointly in bringing about the destruction of the boiler, which will be more or less rapid according to circumstances of design, construction, quality of material, management, etc.

The causes which most affect the integrity of boilers and limit their usefulness, are either inherent in the material or due to a want of skill in their construction and management; they may be enumerated as follows:

First, inferior material; *second*, slag, sand, or cinders being rolled into the iron; *third*, want of lamination in the sheets; *fourth*, the overstretching of the fibre of the plate on one side and puckering on

the other in the process of rolling, to form the circle for the shell of a boiler; *fifth*, injuries done the plate in the process of punching; *sixth*, damage induced by the use of the drift-pin; *seventh*, carelessness in rolling the sheets to form the shell, as a result of which the reams, instead of fitting each other exactly, have in many instances to be drawn together by bolts, which aggravates the evils of expansion and contraction when the boiler is in use; *eighth*, injury done the plates by a want of skill in the use of the hammer in the process of hand-riveting; *ninth*, damage done in the process of calking.

Other causes of deterioration are unequal expansion and contraction, resulting from a want of skill in setting; grooving in the vicinity of the seams; internal and external corrosion; blowing out the boiler when under a high pressure and filling it again with cold water when hot; allowing the fire to burn too rapidly after starting, when the boiler is cold; ignorance of the use of the pick in the process of scaling and cleaning; incapacity of the safety-valve; excessive firing; urging or taxing the boiler beyond its safe and easy working capacity; allowing the water to become low and thus causing undue expansion; deposits of scale accumulating on the parts exposed to the direct action of the fire, thereby burning or crystallizing the sheets or shell; wasting of the material by leakage and corrosion; bad design and construction of the different parts; inferior

workmanship and ignorance in the care and management. All these tend with unerring certainty to limit the age and safety of steam-boilers.

On account of want of skill on the part of the designer and avarice on the part of the manufacturer, or, perhaps, both reasons, boilers are sometimes so constructed as to bring a riveted seam directly over the fire, the result of which is, that in consequence of one lap covering the other the water is prevented from getting to the one nearest the fire, for which reason the lap nearest the fire becomes hotter and expands to a much greater extent than any other part of the plate; and its constant unequal expansion and contraction, as the boiler becomes alternately hot and cold, inevitably results in a crack. Such blunders are aggravated by the scale and sediment being retained on the inside, between the heads of the rivets, which can never be properly removed in cleaning.

The tendency of manufacturers to work boilers beyond their capacity, especially when business is driving, is too great in this country; and no doubt many boiler explosions may be attributed to this cause. Boilers are bought adapted to the wants of the manufactory at the time, but, as business increases, machinery is added to supply the demand for goods, until the engine is overtasked, the boiler strained and rendered positively dangerous. Then, again, it not unfrequently occurs that engines in

manufactories are taken out and replaced by those of increased power, while the boilers used with the old engine are retained in place, with more or less cleaning and patching, as the case may require. Now, it is evident to any practical mind that boilers constructed for a twenty-horse power engine are ill adapted to an engine of forty-horse power, more especially if those boilers have been used for a number of years. In order to supply sufficient steam for the new engine, with a cylinder of increased capacity, the boiler must be worked beyond its safe working pressure, consequently excessive heating and pressure greatly weaken it and endanger the lives of those employed in the vicinity.

The danger and impracticability of using boilers with too limited steam-room may be explained thus: Suppose the entire steam-room in a boiler to be six cubic feet, and the contents of the cylinder which it supplies to be two cubic feet; then, at each stroke of the piston, one-third of all the steam in the boilers is discharged, and consequently one-third of the pressure on the surface of the water before that stroke is relieved; hence it will be seen that excessive fires must be kept up in order to generate steam of sufficiently high temperature and pressure to supply the demand. The result is that the boilers are strained and burned. Such economy in boiler power is exceedingly expensive in fuel, to say nothing of the danger. Excessive firing distorts

the fire-sheets, causing leakage, undue and unequal expansion and contraction, fractures, and the consequent evils arising from external corrosion. Excessive pressure arises generally from a desire on the part of the steam-user to make a boiler do double the work for which it was originally intended. A boiler that is constructed to work safely at from fifty to sixty pounds was never intended to run at eighty and ninety pounds; more especially if it had been in use for several years. Boilers deteriorated by age should have their pressure decreased, rather than increased.

One of the first things that should be done in manufacturing establishments would be to provide sufficient boiler-power, and, in order to do this, the work to be done ought to be accurately calculated and the engine and boilers adapted to the results of this calculation. Steam-users themselves are frequently to blame for the annoyances and dangers arising from unsafe boilers and those of insufficient capacity. For motives of false economy they are too easily swayed in favor of the cheaper article simply because it is cheap, when they should consider they are purchasing an article which, of almost all others, should be made in the most thorough manner and of the best material. In view of the fearful explosions that occur from time to time, every steam-user should secure for his use the best and the safest. The object of a few dollars, as

between the work of a good, responsible maker and that of an irresponsible one, should not for one moment be entertained.

It is very bad policy for steam-users to advertise for estimates for steam-boilers, or to inform all the boiler-makers in the town or city that a boiler or boilers to supply steam for an engine of a certain size is needed, because in this way steam-users frequently find themselves in the hands of needy persons, who, in their anxiety to get an order, will sometimes ask less for a boiler than they can actually make it for; consequently, they have to *cheat* in the material, in the workmanship, in the heating-surface, and in the fittings. As a result the boiler is not only a continual source of annoyance, but, in many instances, an actual source of danger. The most prudent course, and in fact the only one that may be expected to give satisfaction, is to contract with some responsible manufacturer that has an established reputation for honesty, capability, and fair dealing, and who will not allow himself to be brought in competition with irresponsible parties for the purpose of selling a boiler.

There are thousands of boilers designed, constructed, and set up in such a manner as to render it utterly impossible to examine, clean, or repair them. Generally in such cases, in consequence of imperfect circulation, the water is expelled from the surface of the iron at the points where the extreme heat from

the furnace impinges, and, as a result, the plates become overheated and bulge outward, which aggravates the evil, as the hollow formed by the bulge becomes a receptacle for scale and sediment. By continued overheating the parts become crystallized, and either crack or blister; this, if not attended to and remedied, will eventually end in the destruction of the boiler. Many boilers, to all appearance well made and of good material, give considerable trouble by leakage and fracture, owing to the severe strains of unequal expansion and contraction induced by their rigid construction, the result of a want of skill in the original design.

DESIGN OF STEAM-BOILERS.

It has become a general assertion on the part of writers on the steam-boiler that the most important object to be attained in its design and arrangement is thorough combustion of the fuel. This is only partially true, as there are other conditions equally important, among which are *strength*, *durability*, *safety*, *economy*, and *adaptability* to the particular circumstances under which it is to be used. However complete the combustion may be, unless its products can be easily and rapidly transferred to the water, and unless the means of escape of the steam from the surfaces on which it is generated is easy and direct, the boiler will fail to produce satis-

factory results either in point of durability or economy of fuel.

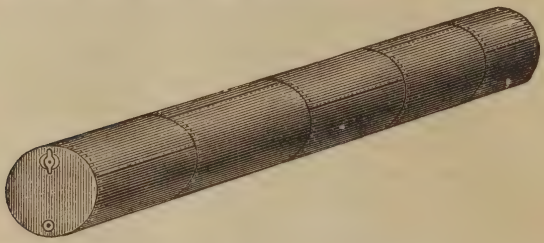
Strength means the power to sustain the internal pressure to which the boiler may be subjected in ordinary use, and under careful and intelligent management. To secure *durability*, the material must be capable of resisting the chemical action of the minerals contained in the water, and the boiler ought to be designed so as to produce the least strain under the highest state of expansion to which it may be subjected,— be so constructed that all the parts will be subjected to an equal expansion, contraction, push, pull and strain, and be intelligently and thoroughly cared for after being put in use. These objects, however, can only be obtained by the aid of a knowledge of the principles of mechanics, the strength and resistance of materials, the laws of expansion and contraction, the action of heat on bodies, etc. The *economy* of a steam-boiler is influenced by the following conditions: cost and quantity of the material, design, character of the workmanship employed in its construction, space occupied, capability of the material to resist the chemical action of the ingredients contained in the water, the facilities it affords for the transmission of the heat from the furnace to the water, etc. The *safety* of any structure depends on the designer's knowledge of the principles of mechanics, the resistance of materials, and the action of bodies as influenced by

the elements to which they are exposed; and in the case of steam-boilers the safety depends on the judgment of the designer, the quality of the material, the character of the workmanship, and the skill employed in the management. Safety is said to be incompatible with economy, but this is undoubtedly a mistake, as an intelligent economy includes permanence and seeks durability. *Adaptability* to the peculiar purposes for which they are to be used is one of the first objects to be sought for in the design and construction of any class of machines, vessels, or instruments, and it is undoubtedly this that gave rise to the great variety of designs, forms, and modifications of steam-boilers in use at the present day, which are, with very few exceptions, the result of thought, study, investigation, and experiment.

FORMS OF STEAM-BOILERS.

According to the well-known law of hydrostatics, the pressure of steam in a close cylindrical vessel is exerted equally in all directions. In acting against the circumference of a cylinder, the pressure must therefore be regarded as radiating from the axis, and exerting a uniform tensional strain throughout the enclosing material. The cylindrical form, whether used for the shell of a boiler in which it is subjected to internal pressures, or for the flues through which the gases escape, or for tubes for the

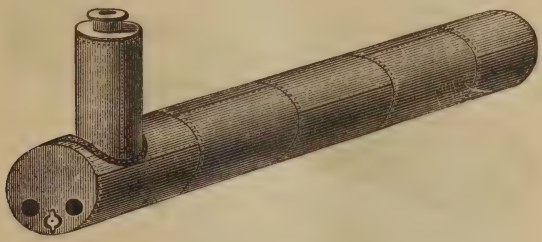
circulation of the water, is the form best adapted for strength, permanence of shape, and cheapness of construction; as flat surfaces, when exposed to high pressures, are positively dangerous, and whenever any departure from the circular form has been attempted, the result has been a failure.



THE PLAIN CYLINDER BOILER.

The plain cylinder boiler, shown on this page, is one of the earliest forms of steam-generators, as well as one of the most simple in construction, and, until quite recently, one of the most extensively used, but it is fast passing out of use, except in localities where economy of fuel is a secondary object. Its advantages were lightness, moderate first cost, and that it afforded better facilities for cleaning, repairing, or the renewal of any of its parts, than any other type of boiler. It also possessed peculiar advantages for rolling-mill and blast-furnace purposes, as it required little care, and was least dangerous on account of the great body of water it con-

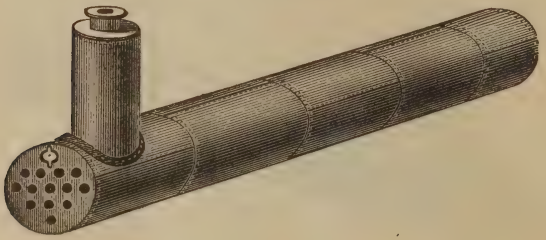
tained. Its disadvantages were its great length, especially in locations where space was of great value; its waste of fuel, arising from its limited heating surface; and the great body of useless water it contained, which had to be heated every time the boiler cooled.



THE FLUE BOILER.

The flue boiler, illustrated above, is a modification of the plain cylinder, and is characterized by an arrangement of one or more flues, generally two, though in some cases three or even five, running longitudinally within the shell through which the smoke and gases from the furnace pass to the chimney. With the same length and diameter, the heating surface is much greater than in the cylinder boiler, consequently it occupies less space, which is an object of great importance in many instances. But it has the disadvantages of extra weight, increased first cost, and that it is more difficult to

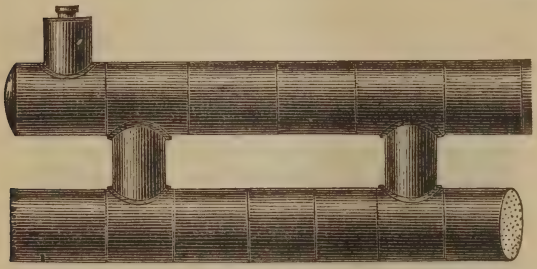
clean or repair. It also requires more care on account of the liability of the flues to become overheated and collapse, in case the regular supply of water should be neglected. Like the cylinder, it is fast being replaced by other forms.



THE TUBULAR BOILER.

The tubular boiler, a cut of which may be seen on this page, is similar to the flue, except that, instead of large return flues, small tubes are used for the escape of the smoke and gases from the furnace to the chimney, and the transmission of the heat to the water. This boiler, with its various modifications, is probably in more general use for stationary, locomotive, and marine purposes, than any other form. Its introduction and employment as a steam-generator formed the basis for some of the most important improvements heretofore made in railroad and marine steam-engineering.

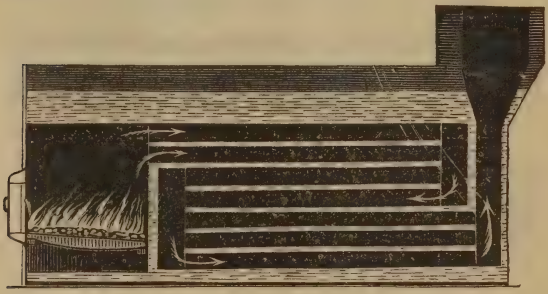
The tubular boiler possesses many advantages, in an economical point of view, over either the cylinder or flue, as it occupies less space, and requires less fuel to evaporate a certain quantity of water in a given time, and in consequence of the small diameters of the tubes, their liability to collapse is entirely obviated. Its great disadvantages are that it is impossible to clean, and in many instances very difficult to repair. It requires equally as much attention as the flue boiler, and more than the plain cylinder.



THE DOUBLE-DECK BOILER.

The double-deck boiler, a cut of which may be seen on this page, is a combination of the plain cylinder and tubular. It consists of a tubular and cylinder boiler, connected together by necks. This kind of boiler presents an immense amount of heating surface, as the heat and gases pass under the tubular boiler,

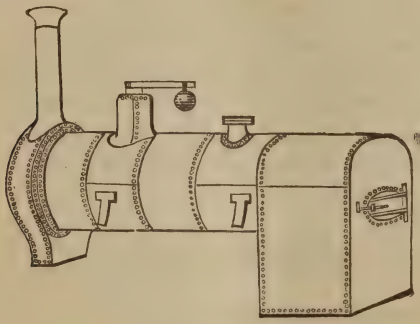
return through the tube, and re-return between the tubular and cylinder shells before passing into the chimney. It requires less attention than either the flue or tubular boiler, as in consequence of the tubular section being continually full of water, and the upper section or cylinder forming the steam-dome, there is very little danger of the tubes becoming stripped. Though it requires considerable room between joints, it occupies less floor space than the tubular. Its disadvantages are its extra weight and first cost, and that it is very difficult to clean or repair.



THE DROP-FLUE BOILER.

Boilers of this class are generally of a large diameter and are internally fired, the furnace being in the front end of the boiler, the smoke and heated gases escaping through the upper flues, returning through the middle flues, and escaping to the chimney through

the lower tier. They are very efficient, and are frequently employed for marine purposes, but are liable to crack and become leaky, in consequence of the unequal expansion and contraction to which the sheets are exposed at the points where the flues return.



THE LOCOMOTIVE BOILER.

The locomotive boiler, a cut of which is shown on this page, though not in very general use for stationary purposes, when well proportioned for its work, is very economical, as it occupies but little space, presents an immense amount of heating surface, steams very rapidly, and, when well constructed, is compact and powerful. This is owing to the fact that the fuel is burned in a metallic fire-box, surrounded by a water-space which absorbs the heat that would otherwise be lost in heating the walls of

a brick furnace, and that the space between the grate-bars and crown-sheet is higher than could be obtained in any other design or form of boiler. This is very favorable to combustion. Another advantage is, that the tubes in such boilers are generally of small diameter and more numerous, which of itself is a great advantage, as small boiler-tubes are capable of producing more satisfactory results than large ones, as they not only increase the amount of heating surface, but at the same time can be made of thinner material. This admits of the heat being conducted more rapidly to the water than if they were large and necessarily thicker.

FIRE-BOX BOILERS.

Fire-box boilers are that class of boilers in which the fuel is consumed in a metal instead of a brick furnace. It includes all locomotives, nearly all marine, and a great many boilers used for stationary purposes; in fact, all internally-fired boilers may be said to be fire-box boilers. A wide difference of opinion among engineers exists in regard to the economy of fire-box boilers; as, while all agree that the fire-box increases the weight and first cost, some claim that more water can be evaporated to each pound of coal in a fire-box boiler than can be done in a brick furnace, as, in consequence of a more extended metallic surface to absorb the heat from the

fuel, more is utilized, and, consequently, less lost: while, on the other hand, it is asserted that the fire-box, though possessing advantages in point of convenience, has none in point of economy, as, if the fire-box was cut away from any boiler, and the shell set up in brick, it would evaporate as many pounds of water to a pound of coal as when it was connected with the fire-box. Besides, the fire-box is likely to corrode, which induces leakage and necessitates repairs.

TUBULOUS BOILERS.

This class of boilers is in very extensive use as steam generators, and, unlike the tubular, they have no shell. In the tubular boiler the tubes serve to convey the flame and heated gases from the fire, and the expansive force of the steam is controlled by the shell as well as by the tubes, the former sustaining an internal pressure, which has a tendency to rupture it, while the external pressure on the tubes has the effect of causing them to flatten and collapse. In the tubulous boiler, on the other hand, there is no shell, properly so called, and the tubes being filled with hot water and steam sustain an internal pressure only, rendering them safer, particularly if the tubes be of small diameter, as it is well known that a tube of a moderate thickness of metal is capable of withstanding with safety a pressure which would utterly destroy a boiler of ordinary size.

FAMILIARITY with Steam Machinery, more especially with Boilers, is apt to beget a confidence in the ignorant which is not founded on a knowledge of the dangers by which they are continually surrounded; while contact with Steam, and a thorough elementary knowledge of its constituents, theory, and action, only incline the intelligent Engineer and Fireman to be more cautious and energetic in the discharge of their duties.

SIZE OF BOILERS.

It is generally understood that the larger a steam-boiler is for the work to be done the more economical it will be of fuel, because the combustion is slower, and consequently more perfect, and the flames and smoke are thus in contact with the heated surface a longer time and therefore impart more of their heat to the water, and that—the water capacity of a large boiler being greater than that of a small one — there is more hot water stored up for use when the maximum power of the engines must be exercised, for which reason the fire need not be forced so much as it would be if it were necessary to generate all the steam consumed at such times as fast as it is used. But it must not be inferred from this that boilers entirely too large for the services they have to perform are economical, as an extra large boiler contains a great body of water and requires an extra quantity of fuel to get up steam every time it is allowed to cool down.

It is not unusual to find manufacturers of steam-boilers recommending a thirty-, or even a forty-horse power boiler for the purpose of supplying steam to a twenty-horse power engine. This is very doubtful economy, as an extra diameter and length of boiler necessitates extra strength of material, which induces extra weight and first cost, and an increased consumption of fuel. A steam-boiler, like any other

machine, should be proportioned to the purposes for which it is intended, and its application to that particular purpose should be the result of mature deliberation, and be based upon sound calculation, and not on custom, hearsay, or any other vagaries that may be popular regarding such things.

It is also quite common for small boilers to be replaced with large ones for the purpose of furnishing an extra quantity of steam, while, perhaps, the same sized grate-bars, same area of flue, and same chimney are used. Such arrangements are generally influenced either by ignorance or avarice, or perhaps by both, and are sure to give rise to dissatisfaction between the boiler-maker and purchaser. Before purchasing a boiler, it is necessary to know the maximum quantity of steam that will be needed, the quality of the fuel, and the character of the draft, etc. These three things intelligently considered and decided upon, the heating and grate surface can be proportioned accordingly, after which, if the management be careful and intelligent, there can be no reason why the boiler should not give satisfaction.

SECTIONAL STEAM-BOILERS.

Sectional boilers consist, essentially, of a system of tubes, so arranged that a continuous circulation of the water is maintained through the tubes from

the mechanical action arising from some portions of the tubes being maintained at a higher temperature than others, the heated and lighter water ascending and the cooler and heavier water descending. The shell is dispensed with, and the heat applied directly by both radiation and contact to the exterior surfaces of the tubes. The idea of sectional steam-boilers is claimed to have originated with Jacob Perkins, about the year 1830, and since that time a great variety of designs and constructions of that class of steam-generators has been tried, and nearly all abandoned. This arose partly from a want of knowledge of the requirements of a steam-boiler on the part of their designers, a want of skill in their construction, as well as from a want of proper tools for their adjustment.

The claim which opened the way for the introduction of sectional boilers, and one on which their inventors and advocates have laid so much stress, namely, that they were non-explosive, and that a tube, or number of tubes, or even a section, might explode and do but trifling damage, has not held good, at least in all cases, as the accidents at Hoopes & Townsend's and at Troth & Gordon's, in Philadelphia, show, several men having lost their lives in both cases; in one, by the explosion of a section, and in the other by the explosion of the whole boiler. Why, in the face of these facts, such boilers should claim to be non-explosive, or safer than ordinary

or wrought-iron boilers, is difficult to see. In their construction large quantities of cast-iron are employed, and, to be of equal strength with the wrought-iron, it must of necessity be a great deal thicker. Now, as it is well known that the thin part of steam-boilers expands more rapidly than the thick, and that the limit of the expansion of the two metals is different, it is plain that some parts of sectional boilers must be subjected to an enormous strain, while the strain on other parts will be only that due to the pressure.

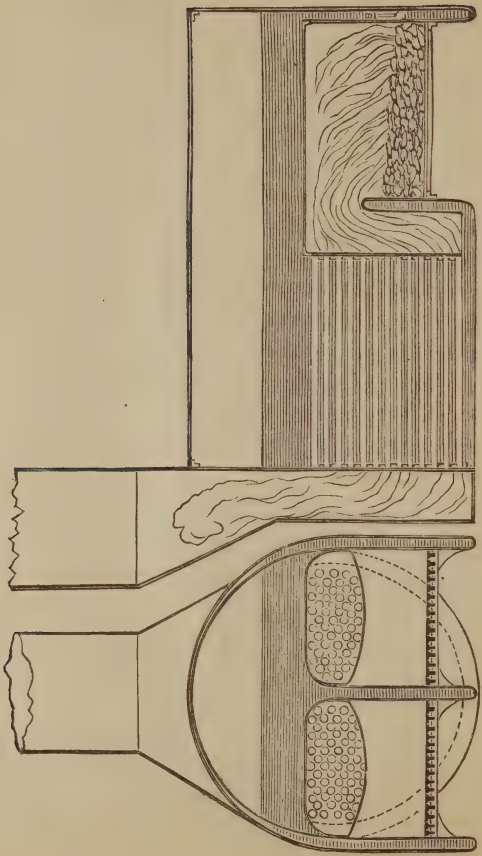
Most sectional boilers have attached to them a wrought-iron steam-drum, which, except for its smaller diameter, possesses all the dangers of the ordinary wrought-iron boiler; and if this drum is constructed of iron of thinner gauge, or is imperfectly made, the liability to accidents is the same as in the case of the wrought-iron boiler. Besides, most sectional boilers are difficult, if not impossible, to clean; their first cost is more than that of the ordinary cylinder, flue, or tubular, while their evaporative powers are, with very few exceptions, less, and it is generally admitted that they are slow steamers. Though they may occupy less ground space than the ordinary form of steam-boilers, they generally require more room between floor and ceiling, while nothing is known of their durability or longevity. Many of the sectional boilers now in use embody in their designs nearly all the bad points of the old-fashioned

wrought-iron boilers, without embracing any of the good ones.

Another great disadvantage inherent in nearly all sectional boilers, and one which entails a good deal of annoyance, and incurs a certain amount of danger, is the great variation in pressure and rapid fluctuation in the water level, whenever they are worked up to their full capacity. That any of this class of boilers now in use will be able to supersede (as was once claimed by their inventors) the ordinary forms of wrought-iron cylindrical boilers, seems very improbable; nor is it at all likely that they will ever be able, in point of durability, efficiency, or economy, to successfully compete with them; still, some recent forms of sectional steam-boilers are creating very favorable impressions.

MARINE BOILERS.

There is now, as there always has been, a great diversity of opinion among engineers in regard to the true principles upon which to design a marine boiler which will produce the greatest effect with the least stowage, first cost, subsequent labor, and fuel. Experience has shown that the best that can be done, is to determine which of these considerations should have the least weight, and as a guide, look to practice rather than any assumed theoretical principles. For land purposes, there is hardly any limit to the size



MARINE TUBULAR BOILER.

or weight of a boiler except first cost. It is easy, therefore, to design and construct one with sufficient heating surface, water-space, and steam-room. But in designing a marine boiler the case is quite different, as the designer is restricted both in room and weight; for if the vessel be occupied or loaded down with boilers, it detracts from the room and capacity that should be devoted to other purposes.

Marine boilers are of necessity either flue or tubular, since the flame must be within the shell of the boiler; but in this arrangement they are almost as various as the makers. The large flue is preferable because less liable to choke with soot, ashes, cinders, or salt which may come from leakage. But in situations which restrict length, height, and width of boiler, the only method of producing in a flue boiler such extent of fire surface as will extract all the heat capable of being used to advantage in generating steam, is to reduce the size and multiply the number of flues. The most ordinary forms of marine boilers are the horizontal and vertical; and, so far as efficiency is concerned, there does not appear to be any great difference between them, where equal surfaces are presented to the action of the fire; but there are many things, particularly in sea-going steamers, to be considered, and for them that boiler is the best which gives equal effect, occupies least space, and affords the best facilities for cleaning and repairs.

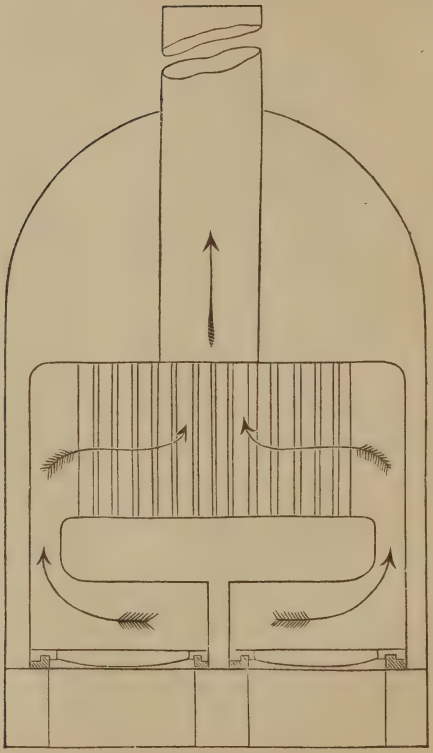
A certain proportion between the area of the grate

and the total heating surface has been found productive of the best results, with a given description of fuel; but any alteration in the quality of the fuel used will be found to affect this result materially. Consequently, no general rule can be laid down for marine boilers that will answer for all kinds of fuel; nor is it at all likely that any one form will ever fulfil all the varied conditions under which such boilers may be placed. A consideration of great importance in the construction of marine boilers is their capacity to contain water and steam. This, of course, depends upon the size of the boiler and the proportion of space occupied by flues or tubes, as, if the space within it be nearly filled with flues, there can be but little room left for water.

In fixing on the proper capacity of the water-space of a marine boiler, there are not such peculiar difficulties as in the case of the steam-chamber, and any one at a first view would say, as many do without sufficient consideration, that there cannot be too little water, provided the boiler is filled to the proper height; for it is quite obvious the smaller the quantity of water the less will be the expenditure of the fuel during the first getting up of the steam after each stoppage of the engine. It is, however, not the "getting up" the steam, but the keeping it up, that ought to be considered of most consequence. It is a prevailing opinion that, after steam is once got up, there is no material difference between keeping a

large quantity of water boiling and a small quantity, provided the escape of heat is prevented by sufficiently clothing the boiler with non-conducting substances; but on this subject engineers differ. Why practical men should differ in opinion on so plain a matter is unaccountable.

The quantity of water carried must exceed that of the evaporation in a given time, in order that the supply of feed-water may not greatly reduce the temperature of the water in the boiler and check the formation of steam. There must in all cases be a sufficient height of water in the boiler to prevent the flues or crown-sheet from becoming bare in case the supply of feed-water be neglected or the vessel pitches in a rough sea. When marine boilers are so constructed that steam cannot be taken off above the level of the water without danger of working water into the steam-cylinder, it becomes necessary to resort to the expedient of attaching a steam-dome to the boiler. This steam-dome is constructed either inside or around the smoke-pipe, and, though not adding much to the cubic capacity of the steam-room, has the effect of superheating the steam, or imparting to it an extra heat, which greatly increases its expansive force, and renders it less liable to condense in the passages between the boiler and the cylinder.



VERTICAL MARINE BOILER.

TABLE

SHOWING THE NUMBER OF SQUARE FEET OF HEATING SURFACE TO ONE SQUARE FOOT OF GRATE SURFACE IN THE BOILERS OF NOTED OCEAN, RIVER, AND FERRY-BOAT STEAMERS.

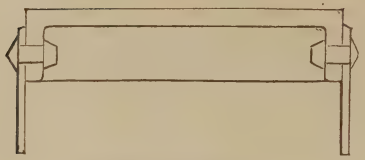
Name of Steamer.	Number of sq. feet of heating surface to 1 sq. foot of grate surface.
Powhatan, U. S. N.	22.3
Susquehanna, " "	25.
Mississippi, " "	18.6
San Jacinto, " "	27.
Saranac, " "	27.25
Princeton, " "	22.
Michigan, " "	19.75
Vixen, " "	16.
Massachusetts, " "	33.6
Georgia, Merchant Steamer	22.25
Washington, " "	23.5
United States, " "	21.9
Northerner, " "	24.9
Falcon, " "	20.8
Philadelphia, " "	21.
Republic, " "	31.
Ohio, " "	22.25
Hermann, " "	30.6
Cherokee, " "	23.7
Union, " "	66.4
Constitution, " "	34.5
Golden Gate, " "	32.8
Monumental City, " "	31.5
El Dorado, " "	26.8
City of Pittsburg, " "	35.5
Pioneer, " "	33.5
Albatross, " "	32.75
Osprey, " "	34.
Humboldt, " "	18.6
Franklin, " "	28.4

TABLE.—*Continued.*

Name of Steamer.	Number of sq. feet of heating surface to 1 sq. foot of grate surface.
Arctic, Merchant Steamer	33.25
Baltic, " "	33.25
Pacific, " "	33.25
Atlantic, " "	33.25
May Flower, " "	31.71
Empire State, " "	24.5
America, " "	32.25
Knoxville, " "	63.1
North America, River Steamer	22.3
South America, " "	24.9
Oregon, " "	31.3
Alida, " "	27.9
Niagara, " "	27.
Joseph Belknap, " "	27.5
Mountaineer, " "	32.
New World, " "	25.17
Traveller, " "	21.3
Isaac Newton, " "	28.2
Roger Williams, " "	19.2
Thomas Powell, " "	25.5
Armenia, " "	24.5
America, " "	26.
Bay State, " "	29.3
Empire State, " "	25.
Baltimore, " "	42.37
J. M. White, Western river Steamer	26.
Rescue, Steam-tug	28.
Anglo-Saxon, "	23.
Merchant, Ferry-boat	38.
Seneca, "	20.
Onalaska, "	19.6
John Fitch, "	22.3
Average	28.08

MANY regard steam as an incomprehensible mystery; and although they may employ it as a power to accomplish work, know little of its character or capabilities. Steam may be managed by common sense rules as well as any other power; but if the laws which regulate its use are violated, it reports itself, and often in louder tones than is pleasant.

BOILER-HEADS.

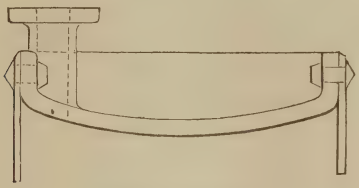


Flat Head turned Outward.

There are two forms of boiler-heads in general use, and four ways in which they are secured to the shell of the boiler. These are — first, the flat head turned outward; second, the flat head turned inward; third, the arched head turned outward; fourth, the arched head turned inward. Considering the two facts, first, that, with a given amount of material, arched forms are stronger than flat ones, and, second, that cast-iron resists compressive better than tensile strains, it plainly appears that the first plan mentioned above is the weakest, and the fourth plan the strongest, mode in which a cast-iron head can be used. It is also true that either form of head is stronger when turned inward than outward. The correctness of these statements, in so far as the strength of the head is concerned, cannot be gainsaid; but there are other considerations besides strength which determine the form of boiler-heads.

The first to be considered is the arched head turned inward; the strongest plan. It will be

noticed that if the head is made of uniform thickness, with a curve at the spring-line of the arch, to secure a sound casting between the head and the sheet, an acute angular space is left, liable to fill up with sediment and harden into scale by the action



Arched Head turned Inward.

of the fire, which is usually severe at this part of the boiler. Experience has shown that the boiler-plates at this point have corroded and burnt out very rapidly with the heads made and inserted in this manner, though the action of the sediment may be prevented by squaring up the head to a right angle with the sheet; but this renders the plate liable to over-heating, from the excessive quantity of cast-iron in contact with it just over the fire. This latter difficulty may, to a certain extent, be overcome by setting the boiler far enough ahead in the front to protect the mass of iron in the head from the severe action of the fire. There are other objections to inserting heads in this manner, such as loss of capacity, etc., resulting from the great space occu-

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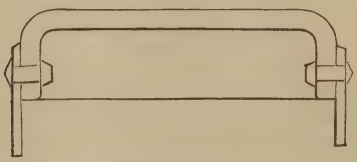
pied by the head in the shell. Now, by adding one-fourth more metal, and distributing it evenly in thickness all over, and giving the head an arched form, it can be turned outward, possess all the requirements of strength needed for safety, and avoid the objectionable features of the concave head.

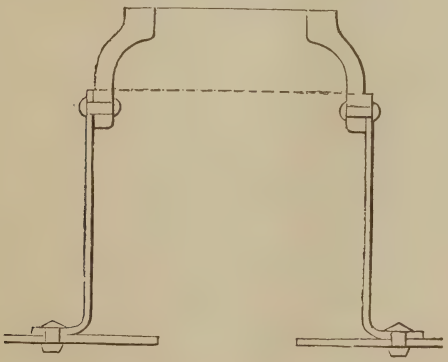
The flat head turned outward possesses more objectionable features than any other form, as it is the worst disposition which can be made of metal to withstand internal elastic pressure, as the tendency of the force within a boiler is to cause the flat end



Arched Head turned Outward.

to bulge outward, and assume the spherical form. This brings a severe strain upon the point of least resistance, as shown in the cut on page 50, and also upon the rivets which join the head to the shell. Whether boiler-heads be turned inward or outward, it is evident that they must possess strength equal at least to that of the metal of the sheet across the transverse rows of rivet-holes, as the section of metal, after punching, is the measure of strength in any boiler without stays. While we may assume that

the head loses the same amount of metal by the rivet-holes, proportional to its thickness, as the sheet does to which it is secured, whatever be the size or number of rivets, we have but to consider, in the comparison of strength, the ratio of thickness of head and sheet and the tensile strength of each material. Wrought-iron heads of the flat, arched, and egg-shaped forms are now very generally used, on account of their great tensile strength, lightness, and the facilities they afford for bracing; more particularly in boilers of a large diameter.



STEAM-DOMES.

The advantages claimed to be derived from the steam-dome are, that it acts as a steam reservoir and also an anti-primer, in consequence of being further

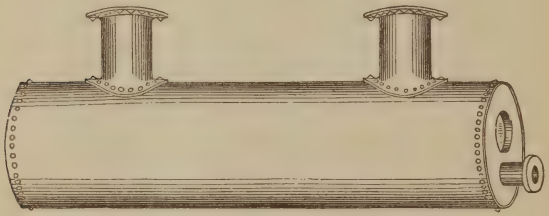
removed from the water than any other part of the boiler, which is true to a certain extent; but, as regards its advantages as a steam reservoir, it can easily be shown that an ordinary sized steam-dome adds very little to the steam-room of a boiler. For instance, a boiler 48 inches in diameter and 20 feet long would contain 251 cubic feet of space; if we take three-fourths of that as water-space, we will have left about 63 cubic feet for steam-room. Now suppose we take a steam-dome 24 inches in diameter and 2 feet high, we gain only 6 cubic feet of space, the steam from which would fill the cylinder of an engine 12 inches in diameter and 24-inch stroke five times, even if worked expansively.

Now, with respect to its advantages as an anti-primer, it appears to be taken for granted that the higher the point at which the steam is taken from the boiler, the drier it is likely to be; but the cooling effect on the steam, by domes of large diameter exposed to the atmosphere, seems to be entirely lost sight of, as it is well known that when an engine is at work, the steam rushes into and through the dome with great velocity, and in its passage is liable not only to take with it a great quantity of water, but have its temperature lowered by coming in contact with so much surface exposed to the action of the atmosphere. It frequently happens that the steam taken from a dome is more wet than that in any other part of the boiler.

The reservoir of power in a boiler is not so much in the steam as in the heated water. With a working pressure of 60 pounds, each cubic foot of steam in the boiler will produce only 4.65 cubic feet of steam, at atmospheric pressure; but 1 cubic foot of water in the boiler will produce nearly 35 times that amount, as at 60 pounds pressure the temperature of the water is 307.5°, or 95.5° above the boiling-point, at atmospheric pressure; and, as every degree of heat added to water already at 212° may be taken as competent to generate 1.7 cubic feet of steam, 95.5° will produce 162.35° cubic feet, or nearly 35 times as much as 1 cubic foot of steam, at 60 pounds pressure. It will be seen from the above that, notwithstanding the general opinion that the presence of a steam-dome is essential for obtaining dry steam and as a remedy for priming, it should be regarded as not only a useless and expensive appendage to a boiler, but a source of real weakness and danger; the practice of cutting a dome-hole in the shell of a boiler, without providing for the weakening of the plate by some other means, should be looked upon as a very mischievous and dangerous practice.

When it becomes necessary to have a dome, as in case of limited steam-room, or where the arrangement of the tubes or flues is such as to make it necessary to carry the water high in the boiler, the hole in the plate under the dome should not be cut

larger than is sufficient to allow a free escape of the steam from the boiler to the dome, or to admit of a convenient adjustment of the dome-braces. In most marine boilers the steam-dome is constructed either inside or around the smoke-pipe, and, though not adding much to the cubic capacity of the steam-room, has the effect of superheating the steam, or imparting to it an extra heat, which greatly increases its expansive force, and renders it less liable to condense in the passages between the boiler and the cylinder.



MUD-DRUMS.

As will be seen by the above cut, the mud-drum is a small cylindrical vessel, ordinarily about twenty-four inches in diameter, attached to the under side of a steam-boiler for the purpose of receiving the feed-water before it enters the boiler, and collecting and retaining the mud or other impurities that may be contained in the water; and also for the

purpose of imparting heat to the feed-water before entering the boiler. When we consider the short life of the mud-drum, which rarely exceeds six or seven years, and also the expense of removing it and replacing it with a new one, its use in any case becomes a question of doubtful economy.

Steam-users and engineers for a long time entertained the belief that mud-drums were beneficial, inasmuch as they imparted extra heat to the feed-water, and retained the mud that would otherwise have been carried into the boiler. Experience, however, has shown this to be a grave error, as mud-drums impart very little heat to the feed-water, and retain nothing but the earthy matter which is held in suspension in the water, while all the destructive carbonates that are held in solution are carried into the boiler. A good deal has been said and written, and many theories advanced, to account for the pitting or honey-combing of mud-drums, but the mysterious manner in which it occurs, and its peculiar character, have not as yet been fully explained, as scientific men are still unable to assign even a plausible cause. The most probable cause for this singular pitting or rotting away might be assigned to the location of the drum, as it receives, on the upper side, nearly all the heat imparted to it, and has not enough on the lower side to keep the iron perfectly dry, and to prevent the rusting of the plates and rivet-heads.

WATER-SPACE AND STEAM-ROOM IN STEAM-BOILERS.

The cubic contents of a steam-boiler may be divided into two parts, namely, that occupied by the water, and that which is occupied by the steam, each of which has, of necessity, a very narrow limit of variation, though they differ very materially for different boilers. In the case of a locomotive, it is almost impossible to fix any ratio whatever between the water-space and steam-room, since the former, of necessity, is limited; and every additional row of tubes to increase the heating surface reduces the area of the water-space. So with the steam-room, to secure dryness of steam and steadiness of action large space is desirable; but it is limited by the same considerations that restrict the water-space.

According to Bourne and Armstrong, the water-space should be three-fourths, and the steam-room one-fourth, the whole internal capacity of the boiler. For the boilers of stationary engines, these proportions give very satisfactory results; and for locomotive and marine boilers two-thirds water-space and one-third steam-room are the proper proportions. In the case of the marine boiler, it is, of course, necessary to have sufficient water to keep the flues and crown-sheets from becoming bare when the vessel is pitching in a rough sea. So also in the case of the locomotive, it is necessary to have sufficient water to cover all the

parts exposed to the direct action of the fire when the engine is ascending or descending steep grades. The proportions of steam-room for all boilers are based on the idea that a certain reserve of steam is desirable in proportion to the amount of water evaporated per hour, and that that reserve should never in any case be less than twelve times the capacity of the cylinder.

DIAMETER AND LENGTH OF STEAM-BOILERS AND THICKNESS OF BOILER-PLATE.

The diameter of steam-boilers must be determined by the ends which they are desired to meet, and the objects for which they are employed; also the tensile strength of the material, and the internal pressure to which they are to be subjected. For the same internal pressure and the same material, the thickness for different diameters must be proportional to the diameters of the boiler; for extra pressures, either the diameter must be decreased, or the thickness of the material increased, which also increases the weight. As the thickness of boiler material for ordinary high-pressure use must range from three-sixteenths to seven-sixteenths of an inch — inasmuch as any material thinner than the former can hardly be calked, and if thicker than the latter is difficult to rivet, except with machinery — the extreme limit to the diameters of boilers for high-pressure steam must

be about sixty inches. The boilers of low-pressure engines are frequently made from one hundred to one hundred and twenty inches in diameter, but they are intended to sustain a pressure of only about twenty pounds to the square inch.

Length of Boilers.— The strength of a boiler to resist internal pressure is not affected by its length, except what is due to the stress or sag, induced by the weight of the boiler itself. Boilers may be viewed as having certain relations to girders in principle. Girders generally have their two ends resting on two points of support, and the load is either located at fixed distances from the props, or dispersed over the whole surface as in the case of the steam-boiler. But, unlike the girder, the boiler is exposed to high temperatures, and to deteriorations induced by the extreme limits of expansion and contraction, which have a tendency to cause it to bend or sag in the middle. It has been demonstrated by practical experiment and observation, both in this country and in England, that there is nothing to be gained by the use of long boilers, and that the extreme length of plain cylinder boilers should never exceed seven times their diameter; of flue boilers, six times; of a tubular and double-deck, five times; and of locomotive boilers, from three to four times their respective diameters.

Thickness of Boiler Materials.— There appears to be a wide difference of opinion among engineers

as to the thickness of the material capable of producing the most satisfactory results in an economical point of view within the bounds of safety. It is generally admitted that the thicker the boiler iron and the poorer its conducting qualities, the greater will be the loss of heat; and that the thinner the material, provided it possesses sufficient strength and good conducting properties, the less resistance is offered to the passage of the heat from the furnace to the water. Boilers made of a superior quality of iron may be thinner and lighter, and consequently more economical as to first cost; but it is claimed, on the other hand, that there is no difference in point of economy between thick and thin plates except in first cost, provided that they are of the same quality; as, while it requires less fuel to raise the temperature of the water to the boiling-point in the thin boiler than it will in the thick one, the latter will generate more steam with a given quantity of fuel in a given time than the former.

EVAPORATION IN STEAM-BOILERS.

As the particles of water rise heated from the bottom of the boiler, other particles necessarily subside into their places; and it is a point of considerable importance to ascertain the direction in which the currents approach the plate to receive heat. A particle of water cannot leave the heated plate until

there is another particle at hand to occupy its position; therefore, unless a due succession in the particles is provided for, the plate cannot get rid of its heat, and the proper formation of steam is prevented. It may be stated, as a general theory, that vaporization does not depend on the quantity of heat applied to the plate, but on the quantity of heat abstracted from it by the particles of water as they successively take their places upon that part to which the fire is applied. It will follow, as a necessary deduction from this fact, that the amount of vaporization of steam generated will depend upon the quickness with which cold atoms of water gain access to the heated portions of the vessels, while the hotter atoms are driven off. An engineer, therefore, will give a careful consideration to the means of promoting that access of the water to one side of the plate and of heat to the other.

Experiments and facts tend to show that every facility should be provided for enabling steam to make its exit from the bottom of the boiler; that ample space should be given at the ends or sides of the boiler for the circulation of the large body of water which, having parted with its steam, is now again returning to the heated plates at the bottom. It is highly desirable that the water should be made to circulate around the sides of the boiler; because, as water almost invariably contains portions of lime and other earthy salts, this sediment will be deposited

on those portions of the boiler where they can do little harm, and away from the tubes, which would be much injured by incrustations. This observation, of course, applies only to those boilers where the fire is located in the middle, or in which it passes through tubes, and where no excessive heat is likely to touch the parts incrusted. It has been proved, beyond doubt, that no boiler can be injured by heat as long as its plates are in contact with water; these points have been settled by a great variety of experiments.

EVAPORATIVE EFFICIENCY OF STEAM-BOILERS.

The evaporative efficiency of a square foot of heating surface varies in different classes of boilers, as well as in the same boiler, under different conditions; in consequence of this, it is difficult to determine the precise area of heating surface necessary for the production of a given amount of steam in a given time. For a given description of boiler, it is evident that the evaporative efficiency will depend upon the ratio between the quantity of coal consumed and the extent of heating surface, the conducting qualities of the material, the difference in temperature between the fuel in the furnace and the water in the boiler, the quality of the fuel and the manner in which it is burned, the thorough mixture

of the products of combustion, and the time the heated gases are allowed to remain in contact with the heating surface of the boiler; as the greater their velocity, the less time they have to impart their heat to the plates or tubes where the length of the surface is constant.

When the heating surface consists chiefly of tubes, as in the locomotive type of boiler, the collective area of the tubes may be diminished without decreasing the extent of heating surface, since the sectional area varies as the square of the diameter, whilst the surface measured by the circumference diminishes simply as the diameter. With the gases passing at the same velocity through two tubes, whose diameters are as 1 : 2, the latter will be traversed, in a given time, by four times the quantity of gases, and will have only twice the surface to absorb the heat. Therefore, to obtain the same evaporative economy as in the small tube, we must double the length of the larger; or, generally speaking, the proportion between diameter and length of tube is constant for the same evaporative efficiency.

The velocity through a tube may be increased either by reducing its area,— the total quantity of gas passing through remaining constant,— or by increasing their draught, thereby so causing a greater amount of gas to pass through in a given time, the area of the tube remaining unaltered. When an increased quantity of gases, of the same density,

passes through a tube in a given time, although there will be a greater absorption of heat, there will still be a loss by the increased amount of heat remaining in the escaping gases; and in order to preserve the same economy, or in order that the heat of the escaping gases may remain constant, the length of the tube must be increased in proportion to the increased quantity of gases passing through.

When we consider the heat to be imparted to the tube-surface by radiation, which, however slight, is probably the principal mode of transfer in vertical and other long tubes, where the convection among the particles of gas cannot be supposed to take place to any great extent, we may assume the heat to be concentrated in the axis of the tube, whence we find the quantity of heat received in a given time by the surface from radiation will be inversely as the square of the diameter. By doubling the diameter, we shall have four times the quantity of gases passed through, and the quantity of heat received in a given time will be only one-quarter of what it was before, owing to the increase of distance. The surface being, however, twice as great, the absorption per unit of length becomes equal to the original. Therefore, in order to bring the evaporative efficiency up to the original, we must double the length of tube or we must increase the heating surface as the square of the diameter, in order to obtain the same evaporative efficiency from radiation when

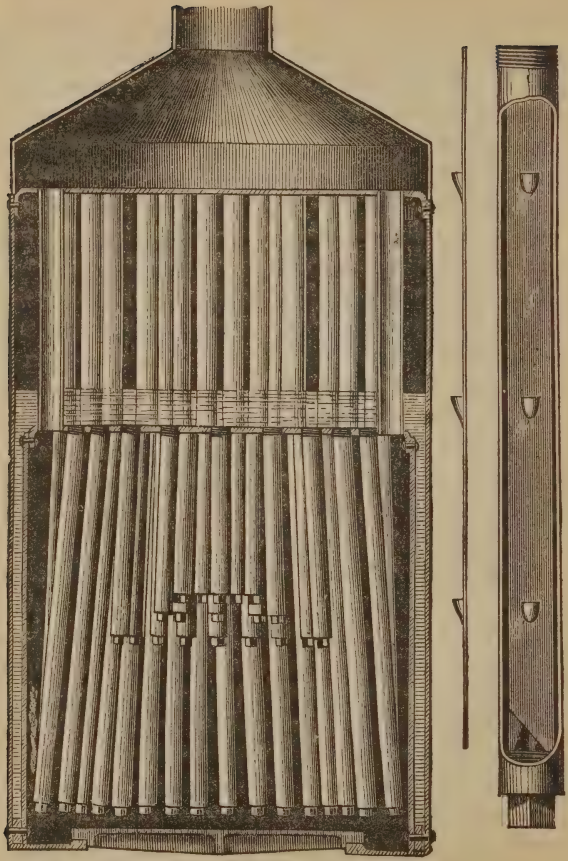
increasing the diameter of a tube. But, if we reduce the diameter to one-half, we increase the absorbing power fourfold per unit of surface; the heating surface being, however, reduced to one-half, the evaporative power of the tube will be only doubled, whence the tube may be reduced to one-half the original length, still retaining the same evaporative efficiency, or, the length remaining unaltered, the quantity of gases passing through should be doubled to maintain the same temperature at the escaping end, or, as before, the efficiency of each square foot of heating surface is increased inversely as the square of the diameter.

The easiest method, and, consequently, the one most frequently adopted, is to measure the quantity of water by the difference of its height in the glass gauge at the beginning and end of the experiment. But this method is very uncertain, as there can be but little doubt that in many boilers the surface of the water is not level, but is generally higher over the furnace, where the greatest ebullition takes place; the difference in the height at any time will greatly depend on the intensity of the firing. Meters are frequently employed for measuring the quantity of water that enters a boiler in a given time; but, like all other contrivances resorted to for that purpose, they are not always reliable. The only sure method of ascertaining the quantity of water evaporated is by actual measurement with a

cistern or vessel whose cubic contents are accurately known. The quantity of water in the boiler, before and after the trial, should be measured at the same temperature, which should not exceed 212°, to in sure accuracy.

But even when the amount of water introduced and the quantity passed off from the boiler are accurately ascertained, there yet remains a doubt as to how much has been actually evaporated, and how much may have passed off in priming, as there are very few boilers that do not prime more or less, and the quantity of water passed off in this manner is sometimes very considerable, and often furnishes boiler-makers, and more particularly manufacturers of patent boilers, an opportunity to delude steam-users with the belief that their boilers are capable of evaporating fourteen or fifteen pounds of water to one pound of ordinary coal.

It has been generally assumed, from the experiments of scientists, that in ordinary practice double the amount of air necessary for complete combustion passes through the furnace. Hence all attempts to reduce the law of evaporations to a standard, which would apply to all boilers, or to frame rules that would be applicable to all conditions of draft, have thus far been based on assumptions which have no precise foundation, as, however thorough and satisfactory the researches of Joule, Peclet, Rankine, and Prideaux may have been in the laboratory,



CLAPP & JONES' VERTICAL CIRCULATING TUBULAR BOILER.

when applied to ordinary practice in mills or factories the results are very different.

The quantity of steam that can be generated in any boiler in a given time is dependent upon a great variety of circumstances, such as size of grate—because more fuel can be burned on a large grate than on a small one—the amount of heating surface, draft, nature of the combustion, firing, arrangements for firing, character and condition of the heating surface, etc. It must also be understood that the larger a boiler is, and the more extensive its heating surface is in proportion to the steam it must generate, the more water it will evaporate per pound of coal, or, in other words, the more economical it will be in its consumption of fuel. The rate of evaporation of different boilers, viz., cylinder, flue, tubular, whether stationary or marine, locomotive or sectional, under the most favorable circumstances, ranges from six to nine pounds of water for each pound of coal burned, and under ordinary circumstances from four to six.

CLAPP & JONES' VERTICAL CIRCULATING TUBULAR BOILER.

This boiler is vertical with fire- and water-tubes. The fire-tubes extend from the crown-sheet of the fire-box up through the top of the shell. The water-tubes are pendant from the crown of the fire-box, the outer

rows extending nearly to the bottom, the inner ones being shorter. By this arrangement, the water is isolated into thin films or sheets, which has the effect of generating steam very rapidly. It is also provided with a peculiar arrangement for the circulation of the water, which is of great importance in boilers of small capacity, that are required to make a large quantity of steam in a short space of time. Steam can be raised from cold water in from four to six minutes from the time of lighting the fire. Another very valuable feature of these boilers is, that they will not foam or prime under the most excessive firing; consequently there is no danger of them becoming overheated or burned, and either fresh or salt water can be used in them without any inconvenience.

METHODS OF TESTING THE EVAPORATIVE EFFICIENCY OF STEAM-BOILERS.

The most general method of testing the evaporative capacity of steam-boilers consists in filling them up to a certain point, in marking the glass gauge at that point when the steam is up to the working pressure, and letting the fire burn nearly out. Then supply it with weighed coal and work it for a given number of hours, noting the water pumped in, and also the coal burned; then the fire is again allowed to burn down to a few embers, and the water is

allowed to come to the same level at which it stood at starting. Then the weight of the water pumped in, divided by the weight in pounds of the coal burned, will give the evaporative economy of the boiler, and the weight of water evaporated per square foot of heating surface per hour will give its absolute evaporative efficiency. This method of testing boilers, though approaching accuracy, cannot be considered absolutely so, as it does not determine the quantity of water that may be primed or carried out with the steam, instead of being evaporated out of the boiler.

Another method is to weigh the water in a tank placed on a platform scale and register, with the thermometer the temperature of the feed meter as it enters the boiler, and the pressure of the steam by the gauge; and in the case of large boilers, where it is inconvenient or impracticable to weigh the water, it can be measured in a tank with tolerable accuracy. This method is open to the same uncertainty as the other, as it only shows the weight of the water pumped in, the quantity of coal consumed, and the pressure of the steam. But it does not show the actual quantity of dry steam, nor the quantity of water that passed over in the shape of spray.

IF Steam-Boilers in general were better cared for than they are, their working age might be greatly increased. Deposits of incrustation, small leaks, and slight corrosion, are too often neglected as matters of little consequence, but they are the forerunners of expensive repairs, delay, and disaster.

PROPORTION OF GRATE SURFACE TO HEATING SURFACE.

The proportion of grate surface to heating surface differs very materially in different boilers. In the locomotive, the proportion is one square foot of grate surface to fifty square feet of heating surface. Marine boilers, about twenty-eight square feet of heating surface to one square foot of grate surface. Plain cylinder boilers, fifteen square feet of heating surface to one square foot of grate surface. Flue boilers, eighteen square feet of heating surface to one square foot of grate surface. Tubular boilers, twenty-four square feet of heating surface to one square foot of grate surface. Sectional boilers, about thirty square feet of heating surface to one square foot of grate surface.

INTERNAL AND EXTERNAL CORROSION OF STEAM-BOILERS.

Internal and external corrosion are two of the maladies that affect the integrity and limit the durability of all classes of steam-boilers, stationary, locomotive, and marine, and their cause and prevention may be said to be among the most obscure subjects in the whole range of steam-engineering.

Internal corrosion presents itself in various forms, each having a peculiar character of its own, though

only sometimes strongly marked; these are designated as uniform corrosion, wasting, pitting, honeycombing, and grooving.

External corrosion is said to be due to galvanic action, or the influence of chemicals and dampness combined. Uniform corrosion is that description of wasting of the plates or tubes, where the water corrodes them, in a more or less uniform manner, in patches of considerable extent, and where there is usually no well-defined line between the corroded part and the sound plate. The presence of this, as well as of other kinds of corrosion, can generally be easily detected, even when covered with a considerable thickness of incrustation, as its presence is often revealed on emptying the boiler by the bleeding, or red streaks, where the scale is cracked; although in some cases, even where the plates are free from incrustation, uniform corrosion, in consequence of its even surface and the absence of any well-defined limit to its extent, may sometimes escape detection.

Even when actually discovered, the depth to which it has penetrated can only be ascertained by drilling holes through the plate and measuring the amount of material remaining. With lap-joints, the thickness remaining at the edge of the plate and round the rivet-heads may serve as a guide to the amount of wasting; but this may prove treacherous, since the adjacent plates may both be corroded to an equal

extent along with the rivet-heads, which will give the edge of the plate the appearance of having the original thickness.

Another peculiarity worthy of notice is the different manner in which the plates and rivet-heads are affected by different kinds of waters after the wasting has been going on for some time. In most cases the corroded iron is readily removed, if it does not come off without means being taken to detach it. But cases are to be met with where the corroded iron adheres tenaciously to the sound plate beneath. In such cases considerable force is required to remove it, and the presence of the corrosion is not suspected until the hammer or pick is forcibly applied.

It frequently occurs that in the case of two boilers alike in every respect, fed with the same water and subject to the same treatment, one may be found attacked at the front end, whilst the other may be affected only on the bottom at the back end.

With the feed-water from one supply only corrosion is found more often under an incrustation of sulphate of lime than under one consisting chiefly of carbonate of lime. In many boilers fed with water containing the former salt, a coating of oxide of iron of a black color may be found adhering to the detached scale, which, as often as it reforms and is broken off, brings with it a fresh film of oxide.

Various means, such as the use of rain, surface, and distilled waters, have been employed for the pre-

vention of internal corrosion ; but they were all found impracticable and generally abandoned, as the expense involved in most cases was found to exceed that of replacing the corroded boiler with a new one, even after a service of only a few years. There does not appear to be any known remedy that affords protection to boilers against this fearful and mysterious phenomenon.

External corrosion is frequently more destructive than internal, particularly in the case of stationary boilers. This probably arises from the fact that its presence is less suspected, and is often less easily detected, in consequence of the covering of brickwork or other material surrounding the shell. The most frequent causes of external corrosion are exposure to the weather, leakage from seams, dripping from safety- or other valves, moisture arising from the ground, either from the damp nature of the location, or from the want of proper appliances to carry off the waste water. A slight leakage from a bad joint may be sufficient to cause a severe local grooving at the seam or flange, as it often goes on for a length of time unperceived and unsuspected, especially when the shell is covered by brickwork or other material to prevent the radiation of heat, as in such cases, if a leak takes place on the upper side of the boiler, the whole circumference of the shell is liable to suffer from it. One of the most remarkable phenomena connected with all kinds of corrosion, is the singular

manner in which they make their appearance and act, affecting very few boilers alike, or even in the same locality.

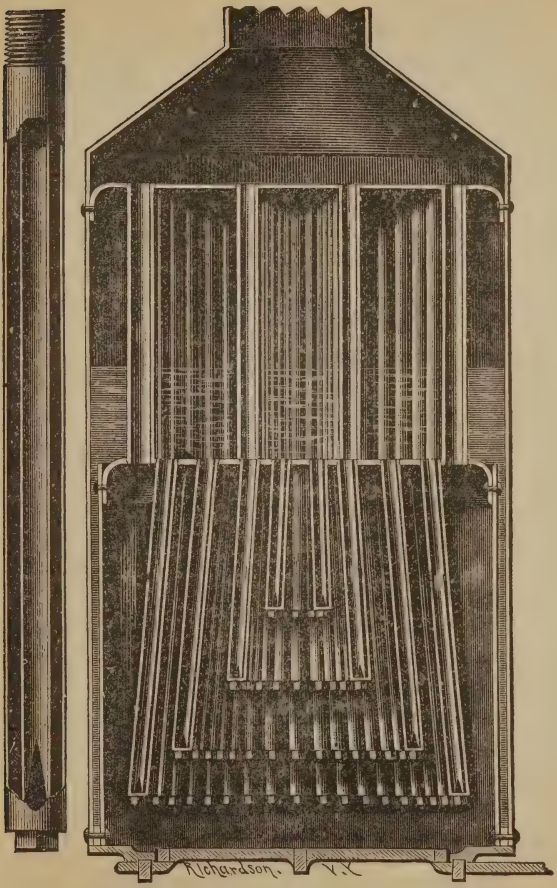
Corrosion of Marine Boilers. — Marine boilers seldom last more than four or five years; whereas land boilers, made of the same quality of iron, often last fifteen or twenty years; yet the difference in durability is not the effect of any chemical action upon the iron by the contact of sea-water, for the flues of marine boilers rarely show any deterioration from this cause; and even in worn-out marine boilers, the hammer-marks on the flues are as conspicuous as at the time of their formation.

The thin film or scale spread over the internal parts of marine boilers would seem of itself to preserve that part of the iron from corrosion which is situated below the water-level; but, strange as it may seem, it is rare to find any internal corrosion of boilers using salt water, in those parts of the boiler with which the water comes in contact; the cause, therefore, of the rapid corroding of marine boilers is not traceable to the chemical action of salt water, as steamships provided with surface condensers, which supply the boilers with fresh water, have not reaped much benefit in the durability of their boilers.

INTERNAL GROOVING IN STEAM-BOILERS.

Among the many defects which are discovered by the inspection of steam-boilers is that of internal grooving or channelling. This is a progressive defect, and always in the direction of danger. It is found running near and parallel with longitudinal seams, and also parallel with girth seams. Various causes have been assigned as the origin of this defect, but there has not been as yet full agreement of authorities as to its real cause. But it is undoubtedly akin to internal and external corrosion, and arises generally from the disturbance of the fibre of the iron, caused by the effort of the boiler, under heat, to adjust itself to certain conditions. Thus a boiler, as is well known, is made of sheets or plates, with the edges lapping one over the other.

It will be readily seen that, no matter how well a boiler is constructed, its form can only approximate to a true cylinder. Hence, under internal pressure, the effort to arrive at a perfect cylindrical form brings an undue strain to bear along the inner edge of the lap, which, by being varied from time to time, under different degrees of pressure, is affected very much as a piece of iron would be by bending it back and forth many times, only in less degree. Now, this continued variation from day to day, year in and year out, disturbs the fibre of the iron along the edge of the lap, and renders it more liable



THE SILSBY VERTICAL STEAM-BOILER.

to the attack of acids in the water. These grooves are generally narrow, and look as though they had been originally cut with a tool; the grooves round the curvilinear seams are caused in a similar way. The heat on the bottom of the boiler expands it more than the other portions, and there is a tendency to cause the boiler to bend back and forth at a point, or at points, at right angles to its length. The fire becomes disturbed and loosened, and is consequently readily attacked by the acids in the water.

SILSBY'S VERTICAL TUBULAR BOILER.

This boiler has water-tubes passing directly through the fire, which are closed at the bottom and open at the top, where they pass through a water-tight plate, and communicate with the water in the boiler. Inside of each water-flue there is a circulating-tube, running the entire length of the flues. By this arrangement a constant current is kept up, the water rising as it is heated to give off its steam, and its place being taken by the cooler current flowing downwards. It is claimed that, by this arrangement, steam can be more rapidly generated than by any other in use.

EXPANSION AND CONTRACTION OF BOILERS.

A great difficulty to be contended with in the management and working of steam-boilers arises

from the unequal expansion and contraction of parts of the structure. In some instances these are so great as to be the cause of more "wear and tear" than any other condition to which the boiler is subjected; consequently, in raising steam in new boilers, or those that have been blown out and allowed to cool down, great care should be taken in allowing the fire to burn moderately, as otherwise the boiler may be seriously weakened, if not permanently injured; more particularly so in the case of flue and tubular boilers, as the flues or tubes, being exposed to the direct action of the fire, and generally of a thinner material than the shell, expand much more quickly, and, as a result, the ends of the boiler are forced outward, and the whole structure exposed to an enormous strain.

When the flues of boilers are placed nearer to the bottom than to the top, the strain, from unequal expansion and contraction, is often such that the plates of the under part of the outer shell are torn or broken; and, in other cases, leaks take place in positions where they are most difficult to discover. When a boiler is set with only a small portion of its bottom exposed to the heat, and a great portion of the structure exposed to the atmosphere, as is the common practice, a powerful agency is left at full liberty to work out most injurious results. The heat will expand that portion of the boiler to which it is applied, while the other portion, exposed to the cold

atmosphere, will contract. Thus the two forces are left to exert their respective powers against each other, tending to tear the boiler asunder by means almost imperceptible.

A boiler under steam is often strained, especially in a longitudinal direction, more by the greater dilation of the tubes compared with the shell, or by the unequal expansion of the top and bottom of the shell, than by the actual steam pressure. The persistent leakage often experienced at the seams, along the bottom of horizontal internally-fired boilers, may in most cases be ascribed to the difference in temperature of the water and steam at the bottom and top of the boiler; but in some cases the leakage is principally caused by the longitudinal straining of the bottom of the shell, due to the greater expansion of the tubes, especially when the firing is forced in getting up steam after the boiler has been at rest. As this straining would not take place in testing the boiler by hydraulic pressure in the usual manner, this leakage would not be produced. It follows, from the above considerations, that a hydraulic test might fail to indicate weakness which would be produced and made apparent by steam pressure.

Boilers are frequently set with the upper surface exposed to the atmosphere, and when the under surface becomes heated, it expands rapidly, while the upper portion, exposed to the cold atmosphere, if it does not positively contract, will expand but slightly;

thus these two forces are left to exert their respective powers against each other, tending to tear the boiler asunder; and the ultimate result is, not unfrequently, an explosion. Iron expands in volume one eight-hundredth, or, in other words, a bar of iron, one inch square, and eight hundred inches long, would expand one inch in length, while heated from the freezing- to the boiling-point of water. The proportion of expansion for any length of bar, corresponding to any length of boiler, can be easily estimated. It is not to be understood, however, that the maximum expansion would occur in boilers generally, for it is rare that one is allowed to get so low in temperature as thirty degrees; still, in the winter season, boilers, when "blown down," are liable to become very cold.

HEATING-SURFACE OF STEAM-BOILERS.

The heating-surface of a steam-boiler may be defined as all those parts of the *shell, flues, tubes, fire-box, crown-sheet,* and *tube-sheets*, with which the heated gases, in their escape from the furnace to the chimney, come in contact; and the heat is transmitted to the heating-surface in different ways, by radiation and contact, and from different hot masses; by contact with the solid, incandescent fuel in the furnace; and by radiation of the flame and gases beyond the bridge-wall, or tube-sheet.

The amount of heat transmitted by radiation from one body to another diminishes as the square of the distance between the bodies increases. The effect on any surface is also diminished by any increase in the inclination at which the rays fall upon it. The radiation from solid, incandescent fuel is greater than from flame, whilst transparent, hot gases scarcely radiate any heat at all. The more intense the contact heat of the flame is by thorough mixture with the air, the less is the heat by radiation. Conduction is the transfer of heat, either between the particles of the same body, or between the parts of different bodies in contact, and it is distinguished, respectively, as internal and external conduction. The rate at which the former takes place in metal plates exceeds very much that of the latter, in which the heat passes from the hot mass to the plates, and from these again to the water.

The efficiency of any heating-surface may be defined as the proportion borne by the amount of heat it transmits to the whole amount available for transmission. A flat, horizontal surface, not too far above the layer of fuel, is usually considered to be the most favorable for raising steam. By being made concave to the fire, it has, however, the further advantages of being still better adapted for receiving the radiant heat; of facilitating the access of fresh supplies of water to replace the heated, ascending particles, and thereby promoting the circulation; of

boiling off the matters deposited from the water, and so preventing incrustation; and of being stronger, and, in some cases, more durable.

Next in efficiency to the flat surface, with the water above, comes the sloping surface surrounding the fire, which is superior to a vertical one, as it receives the rays of heat at a more favorable angle, and allows the steam bubbles to escape more freely. The value of horizontal surfaces beneath the fire is not worthy of consideration as heating-surface. In externally-fired boilers the heating-surface is usually convex to the fire. This is, by many, regarded as inferior to a concave surface, probably because it is not so well adapted for directly receiving the radiant heat from the fire, and does not appear to offer an equal facility for circulation. The results obtained from this description of surface, in actual work, do not appear to verify this conclusion, as it is generally admitted that a convex surface, and not a concave one, is the best form for flame and heat to impinge against, and hence a large, convex surface, or a series of small convex surfaces, will give the best results, and, other things being equal, prove the most economical and effective. Where the products of combustion pass through a number of tubes, as in tubular boilers, the most effective heating-surface, after the bottom of the shell, is of course the top of the tubes, the lower or bottom part being of little avail. The question of the relative effectiveness of

convex and concave heating-surfaces is one which should be thoroughly tested.

There seems to be a wide diversity of opinion among engineers as to what portion of the shell, flues, and tubes of steam-boilers should be recognized as heating-surface, in estimating the horse-power, or, in other words, as their theoretic evaporative capacity. Some portions of the heating-surface of all steam-boilers are exposed to the direct action of the fire, while the heated gases only come in contact with others, the area differing in different boilers. For this reason it has frequently been suggested that the heating-surface of boilers should be divided into what might be termed direct and indirect heating-surface. The direct heating-surface in some boilers is about one-sixth, while in others it is from one-seventh to one-eighth, and in some instances one-ninth, of the entire superficial area. The direct heating-surface is the more efficient, and the lower side of flues and tubes of horizontal boilers is less efficient than the upper side, as, when they become covered with a stratum of ashes, they are of very little value; the same thing may be said of the shells and tube-sheets of boilers when they become thickly coated with soot or ashes, as is frequently the case.

But there are certain difficulties in the way of separating the heating-surfaces into two different parts, and of estimating the relative value of such,

because, if the under side of flues and tubes is to be left out, the question will arise, what has become of the heat transferred within? There was some heat transferred, however inefficient or foul the flues or tubes may be. The crowns and tubes of vertical boilers may be said to be all direct heating-surface, but vertical tubes are less efficient than horizontal, when the conditions are the same.

In estimating the heating-surface of steam-boilers, it is best to include all the surfaces exposed to the direct action of the fire and in contact with the heated gases, otherwise it would be difficult to determine the relative evaporative efficiency of steam-boilers, as compared with their heating-surface; besides, it would give rise to an endless discussion as to what portion should be termed direct, and what indirect, and their relative value and other perplexing questions.

RULES FOR FINDING THE HEATING-SURFACE OF STEAM-BOILERS.

Rule for Locomotive or Fire-box Boilers. — Multiply the length of the furnace-plates in inches by their height above the grate in inches; multiply the width of the ends in inches by their height in inches; multiply the length of the crown-sheet in inches by its width in inches; also the combined circumference of all the tubes in inches by their length in inches;

from the sum of these four products subtract the combined area of all the tubes and the fire-door; divide the remainder by 144, and the quotient will be the number of square feet of heating-surface.

Rule for Flue Boilers.— Multiply $\frac{2}{3}$ of the circumference of the shell in inches by its length in inches; multiply the combined circumference of all the flues in inches by their length in inches; divide the sum of these two products by 144, and the quotient will be the number of square feet of heating-surface.

Rule for Cylinder Boilers.— Multiply $\frac{2}{3}$ of the circumference in inches by its length in inches; divide this sum by 144, and the quotient will be the number of square feet of heating-surface.

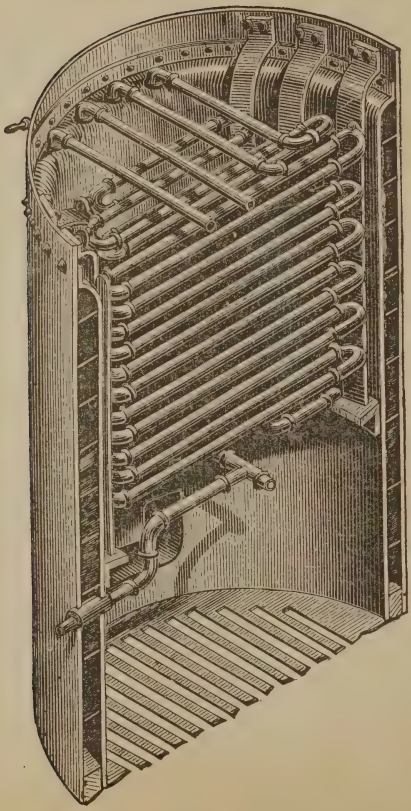
Rule for Tubular Boilers.— Multiply $\frac{2}{3}$ of the circumference of the shell in inches by its length in inches; multiply the combined circumference of all the tubes in inches by their length in inches. To the sum of these two products add $\frac{2}{3}$ the area of both tube-sheets; from this sum subtract the combined area of all the tubes; divide the remainder by 144, and the quotient will be the number of square feet of heating-surface.

Rule *for finding the Heating-Surface of Vertical Tubular Boilers, such as are generally used for Fire-engines.*— Multiply the circumference of the fire-box in inches by its height above the grate in inches. Multiply the combined circumference of all the

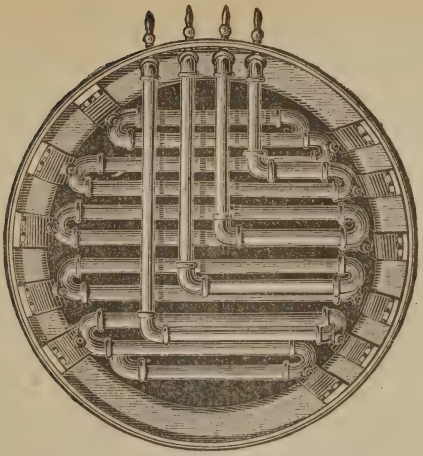
tubes in inches by their length in inches, and to these two products add the area of the lower tube- or crown-sheet, and from this sum subtract the area of all the tubes, and divide by 144. The quotient will be the number of square feet of heating-surface in the boiler.

THE LATTA STEEL COIL-BOILER.

The cuts on pages 90 and 91 represent the Latta Steel Coil-boiler, which, it will be understood, is an upright; but with this exception, it differs from any other steam-generator now in use. It consists of a steam- and water-space, which forms the fire-box, inside of which is securely fastened a coil, through which the feed-water is forced; thus giving an abundance of heating-surface, without any danger of burning the parts most exposed to the fire; and as the coil has plenty of room in which to expand and contract, it obviates the evils resulting from undue strains induced by unequal expansion and contraction. The water is supplied to the coil by a pump, which makes a forced circulation, — this being the quickest way known to make steam, and has the additional advantage of never allowing any sediment or scale to collect in the tubes, which must necessarily increase the durability of the boiler. The shells are cylindrical, and are made of the best steel-plate and the most excellent workmanship. They are very effi-



SECTIONAL VIEW OF THE LATTA STEAM-BOILER.



TOP VIEW OF THE LATTA STEAM BOILER.

BOTTOM VIEW OF THE LATTA STEAM BOILER.

cient, as steam can be raised on them, from cold water, in from three to four minutes.

HORSE-POWER OF STEAM-BOILERS.

There is not at the present time, nor has there ever been, any fixed rule in this country, or in England, for estimating the horse-power of steam-boilers, — that is to say, any rule universally recognized by the trade. It has long been a custom in England to estimate the horse-power of boilers for stationary engines by their length, regardless of the diameter and other conditions. In marine engines we find some makers estimating their power entirely by the grate-surface, one maker dividing his grate area by .8 and calling the result a horse-power, another by .75, and another by .5. Thus a boiler with 100 square feet of grate-surface may be called 125, 133, or 200 horse-power. Others, again, neglect grate-surface altogether, and calculate by the heating-surface, anything between 12 and 25 feet being said by different makers to represent a horse-power.

More recently the evaporation of one cubic foot of water per hour has been generally adopted as a standard for a horse-power in steam-boilers. This rule assumes that the flues are of adequate size and form to afford sufficient draft; that the fuel is of average quality, and that the area of the grate is sufficient for the consumption of at least seven pounds

of anthracite coal per square foot per hour, or other combustible fuel equal in value to that amount. It may be admitted that a cubic foot of water evaporated into steam is an abundance for one actual horse-power, even when used at a very low pressure, and in the cylinder of an engine without expansion, but when used at a high pressure and worked expansively, it will yield in the best class of engines one and a half to two horse-power. Under the most favorable circumstances the area of grate-surface and the square feet of heating surface required to evaporate a cubic foot of water would be about ten square feet of heating-surface and one-half square foot of grate-surface; but there are few very favorable circumstances connected with the economical working of steam-boilers, as there are many agencies at work tending to counteract this result, amongst which may be mentioned the conducting power of the material of which the boiler is made, the condition of the internal and external surface of the boiler, the method of applying the heat to the heating-surface, the temperature of feed-water, and the skill employed in care and management.

Certain vague notions have long existed among engineers and steam-users that in adjusting the dimensions of steam-boilers it is better to have them larger than is absolutely necessary, and it has grown into a custom to recommend a 15-horse power boiler for a 10-horse power engine, a 25-horse power boiler for a 20-horse power engine, and so on.

This rule works well for the seller, but it does not always work both ways, as boiler-makers very often deceive purchasers in the extent of heating-surface they ought to receive, such misrepresentations creating mutual distrust, disappointment, and dissatisfaction. It seems rather singular that all the ordinary rules of trade should be reversed when the question becomes one of the purchase or sale of a steam-boiler, and that the relations of the buyer and seller should not be conducted in accordance with the established standards of pounds, tons, feet, yards, gallons, or even capacity, but that the purchaser offers so much money for material or work to the seller, and both understand by custom that the boiler should have a certain capability, which they term the horse-power.

The recognized rule in this country, after calculating the entire heating-surface, is to allow for cylinder boilers 15 square feet of heating-surface, 1 square foot of grate-surface; for flue boilers, 15 square feet of heating-surface, and $\frac{3}{4}$ square feet of grate-surface; and for tubular boilers, 15 to 16 square feet of heating surface, and $\frac{1}{2}$ of a square foot of grate-surface for each horse-power; a more liberal allowance of grate-surface would insure more satisfactory results. Attempts have been made at different times by scientific men to disregard proportions in estimating the power of steam-boilers, and to discontinue the term horse-power as a misnomer, having no defi-

nite meaning; but as the foregoing proportions have given general satisfaction to both purchaser and seller, and are recognized and well understood by mechanics, it would be almost impossible to change them. Although, like the term horse-power as applied to the steam-engine, they may not be an exact standard of what they are intended to represent, yet they are so interwoven in the mechanical questions of the country, and there are so many interested in preserving the term horse-power, that any attempt to abolish it, or to reject the proportions which custom has so long recognized, would be productive of great confusion both to practical men and mechanics.

The settlement of the question of the horse-power of steam-boilers, or the establishment of a standard that would apply, if not to all, at least to the best known and most generally used types, is very much to be desired. This can only be done by practical experiment, as the results produced in a small, clean vessel of high conducting power, placed over a fire of pure carbon, with the most accurate method of regulating the quantity of air admitted, even though conducted by such scientists as Rankine, Ure, Peclet, Box, and others equally distinguished, can hardly be said to be admissible, when compared with ordinary practice. Such experiments are interesting, inasmuch as they go to show the efficiency of a certain area of heating-surface, and the quantity of heat and of work stored up in good fuel, but they

form no precedent for ordinary practice, as the conditions under which they are tried never exist in the steam-boilers used in mills and factories; besides, the calculations necessary to convert such results into fixed standards, if at all understood, are not much relished, being too complicated for engineers in general.

There are certain difficulties to be encountered in adjusting or fixing a standard for the horse-power of steam-boilers, that would apply to all and meet with universal recognition, which the engineers and scientific men of the past or the present have not been able to successfully overcome, nor is it at all likely that they ever will be. It seems an experience of seventy years has not shed much light on this subject; proof of this may be found in the fact that as often as the subject of the adjustment of the horse-power of steam-boilers is revived, Watt and Smeaton are quoted as high authority, and they undoubtedly are, as very little is known on the subject at the present day beyond that which was understood in their days. Such quotations furnish a virtual acknowledgment that, notwithstanding all the experience of the past, in addition to more modern improvements in the quality of boiler material, in designs, in the character of the fuel and skill of management, the results are as unsatisfactory, and there is as great a diversity of opinion existing on that subject at the present day as there was in the days of Watt.

EXAMPLE.

Diameter of boiler, 48 inches.
Length " " 11 feet.
46 3-inch tubes.

3)150.7968 circumference of shell.
50.2656
2
100.5312
132 length in inches.
2010624
3015936
1005312
13270.1184 sq. in. heating-surface in shell.

9.4248 circumference of 1 tube.
46
565488
376992
433.5408
132
8670816
13006224
4335408
57227.3856 sq. in. heating-surface in tubes.

3)1809.5616 area of 1 tube-sheet.
603.1872
2
1206.3744
2
2412.7488 sq. in. heating-surface in tube-sheets.

7.0686 area of 1 tube.
46
424116
282744
325.1556 area of tubes.
2
650.3112

13270.1184
57227.3856
2412.7488
72910.2528
650.3112.

144)72259.9416 total heating-surface in sq. in.

16)501.8 sq. ft. of heating-surface.

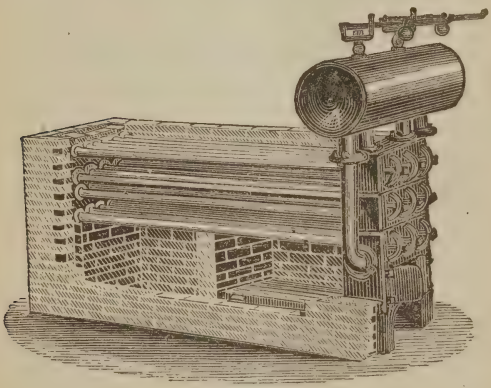
31. horse-power.

Grate-surface required, 15½ square feet.

THE MOORHOUSE PATENT SECTIONAL BOILER.

This boiler consists of several cast-iron tanks, divided transversely one above another. The connections between the apartments are made from the back part of the tanks which forms the tube-sheet. The tubes are accurately tapered to fit corresponding openings in the tube-sheet, and are drawn in by means of brass nuts. The connections between the tubes of the upper and lower apartments being made with return bends of the lowest tubes, while those of the next upper apartment are made with

return bends of the next upper tubes; similarly, those of the third apartment are made with return bends of the third tier or row of tubes, and so on till the upper apartment is reached, the tubes of which are connected to the steam-drum by two necks, any water carried up with the steam being returned to the lower apartments by side return-



pipes. It is claimed that by this arrangement the circulation through the tubes is very rapid, so much so, that all deposit is prevented from settling on the parts of the boiler most exposed to the fire, but is carried into the tank apartments, where it settles, from which it may be blown out through the blow-out pipe. It is so designed and arranged as to afford the most ample and convenient facilities for

cleaning, repairing, or renewal of any of its parts. It is in very general use, and has a reputation second to no other sectional boiler in the country for durability, efficiency, and economy; besides, it is claimed to be non-explosive.

SETTING STEAM-BOILERS.

While engineers differ very much in opinion respecting the best manner of setting boilers, they all readily allow that the results obtained, as regards economy of fuel and the generation of steam, depend in a great measure on the arrangement of the setting. Particularly is this the case with horizontal tubular boilers, and there have been numerous plans introduced to obtain a maximum of steam with a minimum of fuel. Some of the most practical designs and best laid plans are frequently rendered useless for want of knowledge on the part of those whose duty it is to execute or carry them out. This has perhaps been more frequently the case, as regards the setting of steam-boilers, than any other class of machines, as it is customary for owners of steam-boilers to depend too much on the knowledge of masons and bricklayers; consequently, a great many blunders have been made which necessitated changes in the size of grate-bars, alteration of brick-work, alteration of flues, chimney, &c., with a list of other annoyances, such as insufficiency of steam, poor draught, or something else.

In setting or putting in boilers, all the surface possible should be exposed to the action of the heat of the fire, not only that the heat may be thus more completely absorbed, but that a more equal expansion and contraction of the structure may be obtained. When convenient, it will be found advantageous to return the draught through a brick flue, over the top of the boiler, in order to equalize the heat, and consequently the expansion; and although this arrangement does not facilitate the generation of steam, yet fuel will be saved by a more complete application of the heat, and the prevention of radiation from the upper part of the boiler. But the flame should never be allowed to strike the shell or any part of the boiler above the water-line. Many of the best boilers in the country have been ruined by being so set that the flame from the fire enveloped the whole boiler in order to superheat the steam. While it may be admitted that the steam can be superheated or dried in this way, it is always done at the expense of the boiler.

Long boilers are often hung by means of loops riveted to the top of them and connected to cross-beams and arches, resting on masonry above them, by means of hangers. This is a very mischievous arrangement, unless turn-buckles, or some other contrivance, are used to maintain a regular strain on all the hangers, as long boilers, exposed to an excessive heat, are apt to lengthen on the lower

side and relieve the end hangers of any weight; consequently, the whole strain is transmitted to the central hanger, which has a tendency to draw the boiler out of shape — in many instances inducing excessive leakage, rupture, and eventually explosion.

The most permanent practical method of setting boilers is to rivet cast-iron brackets or knees to their ends and centre, about twelve feet apart, resting on brick piers, as by this arrangement one end can settle without injuriously affecting the other. These brackets, in some instances, rest on small rolls arranged in a flanged seat, in order to prevent the piers from being forced out when the boiler expands. Boilers should be set with as little brickwork in contact with the shell as practicable.

Convenient openings should be arranged in the brickwork to facilitate the cleaning of the boiler on the outside, as that part of the shell exposed to the action of the draught is liable to become permanently coated with soot and ashes, rendering a great portion of the heating-surface nearly worthless. The difficulty experienced in removing these non-conductors from the under side of the boiler, generally arises from an improper arrangement at the time of the setting and a want of space.

Some boilers are so injudiciously and improperly set that a great amount of heat passes up the chimney and is lost; while the setting of others is so arranged that it is impossible to either clean, examine,

or repair them. Boilers should never be located in dark cellars, under sidewalks, or in out-of-the-way places, as when so placed they obstruct the light, which is so essential to a close examination of all the parts; besides boilers located in dark and damp places, corrode and waste away more rapidly than most people are aware of.

TESTING STEAM-BOILERS.

Experience has shown that, let a boiler be ever so carefully designed and constructed, there will still remain an element of doubt as to its actual strength, since the material may have sustained injuries in the process of construction, which may have escaped detection. In the case of a new boiler, even by a first-rate manufacturer, to say nothing of original and hidden flaws in the plates and castings, there is always a possibility of defects, such as bad welding, careless riveting, plates burnt in flanging, or cracked in bending, and many other defects that may be traced to reckless negligence or want of skill; **consequently the only means** we have of ascertaining, with any degree of certainty, the safety of a boiler, is by the application of cold-water pressure, as many cases of dangerous defects, which the strictest scrutiny of the practical boiler-maker failed to detect, have been brought to light by means of the hydraulic test.

There are many forms of boilers which do not admit of anything like a proper examination, as, for instance, tubular boilers, in which the shell of the boiler is filled with tubes nearly to the water-line; also, many forms of marine boilers, whose construction is so irregular and complicated as to defy even an approximate calculation of their strength or condition. With regard to the various modes of testing, by hydraulic pressure, that commonly adopted is to pump water in until the desired pressure be reached. The condition of the joints and rivets is then looked to, and any very conspicuous distortion, leak, or defect marked; and in cases of permanent distortion, or flattening of tubes or flues, the injured parts should be immediately removed and repaired, or renewed, as the injury to the tube or flue is liable to be aggravated by subsequent tests, and eventually result in rupture or collapse.

Some advocate the method of marking the leaky joints while the pressure is on, and then lowering the pressure for the purpose of calking; this is decidedly wrong. Boilers should never be calked while under steam- or water-pressure, however light, as the jarring induced by the calking is liable to spring the seams, and cause fresh leakage in different parts of the boiler. The employment of hot water for testing boilers is also recommended by some, as it assimilates, more than cold water, the conditions under which the boiler is placed when at

work. But the water for test should never be more than moderately warm, as the hydraulic test is comparatively worthless, without a thorough examination of the boiler at the same time; and it is impossible to do so in cases where hot water is used, in consequence of the presence of so much heat under and around the boiler.

In some cases, the plan has been adopted of filling the boiler with water, closing every outlet, and putting fire to it. As water expands about $\frac{1}{24}$ in volume in rising from 60° to 212°, the rise of temperature, as the water becomes heated, will cause a corresponding increase of pressure, and, from the regularity with which the pressure rises, any leak that may occur in the boiler will be easily noticed by the jerks or starts of the steam-gauge hand. But the wisdom of this method is extremely doubtful, as it involves a certain amount of danger, and prevents the possibility of examining the boiler in the parts most likely to be affected during the test. In whatever manner a boiler is tested, great care should be taken to obtain the exact amount of pressure employed, for the reason that safety-valves are very often unreliable, particularly so when water-pressure is used, and spring-gauges are not always to be trusted, under such circumstances; in all cases, when the cold-water test is applied, two gauges should be used; for, although a boiler cannot explode under the hydraulic test, yet many serious accidents have

occurred by boilers giving way under such circumstances.

The hydraulic test meets with opposition from some engineers, on the ground that it does not tell the actual strength of the boiler; but the same objection might be urged against the steam and expansion tests, as there is no accurate method of ascertaining the strength of a boiler but to burst it. The hydraulic test is not meant for perfectly sound boilers, but for the detection of weaknesses in certain parts, and is generally successful for that purpose, if well conducted. The injuries arising from an excessive application of the hydraulic test are most likely to occur to flue boilers, as, whenever flues subjected to external pressure depart from the true cylindrical form, or form of greatest resistance, they are liable to collapse, even under very low pressure.

The Sound Test.— The sound test is the most reliable of all tests for boilers, when applied by competent persons. The experienced boiler-inspector can easily tell by the sound on his ear whether the parts subjected to the blow be sound or not, as all the parts that are perfectly sound and in place will ring like a bell, whilst the defective parts will vibrate with a slow and dull sound, like a loosened cord. The sound test should, by all means, be applied to all accessible parts of the shells, crown-sheets, crown-bars, angle-irons, crow's-feet, and braces of every description, as it is of the utmost importance

that all the braces in a steam-boiler should be sound and taut, since they are only substitutes for real strength in some part of the structure, and are frequently very poor ones at that, as the ignorant manner in which they are frequently applied, and the fact that they are, in many instances, allowed to become slack, render them insecure, if not positively dangerous.

REPAIRING STEAM-BOILERS.

The principal causes of loss and danger in the use of the steam-boiler, arise from delay in making timely repairs, and also from the injudicious manner in which the repairing is done. It is often thought that a botch will do just as well as a more skilled and costly mechanic; this is a mistake, as nowhere is the ready command of resources, knowledge of the adaptability of means to ends, skill of eye and hand, common sense and sound judgment, which go to make up an accomplished mechanic, more necessary than in repairing, inasmuch as it is not the same old routine day after day, by which men become mere machines instead of original thinkers, which is required, as every job varies in some particular from every other, and each must be repaired in a different way. It requires brains as well as manual skill to do this kind of work in a creditable manner, and every owner of a steam-boiler or steam-engine will

find it good policy to put his repairing in the hands of a practical mechanic.

It is both good policy and economy to repair as soon as anything is out of order; this is particularly true in the case of steam-boilers. As when allowed to run as long as they will, or until they are considered dangerous, aside from the danger, it is often found impossible to render them safe or serviceable again. A defect which would have cost but a trifle to repair in the first place, owing to neglect, frequently necessitates the replacing of the whole boiler.

When putting a patch on a boiler, the defective parts should be cut out, and the part cut out should be as nearly round as circumstances will permit; a square hole should never be cut in any boiler, but when of necessity it has to be done, rounded corners should be left.

When it becomes necessary to put a new sheet on an old boiler, it is advisable to have the new plate a little thinner than the old one, and it should be so arranged that the calking may be done on the new iron. After repairing a boiler it should always be tested with cold water. Never place the edge of the laps towards the fire, unless they are a considerable distance from it. Cracks running from hole to hole in boiler-seams are more dangerous than those that run towards the centre of the plate or outer edge of the lap. Short cracks may be prevented from

extending by drilling a hole in the end so as to completely drill out the crack, and then inserting a rivet in the hole. Whenever a leak occurs under a lap or seam round any rivet, stay-bolt, or base, entering the steam-room or water-space of a boiler, stop it immediately and have it repaired, as the plate in the neighborhood of the leak wastes away very rapidly.

A great portion of the repairs heretofore done on steam-boilers has been executed on Sunday, which is decidedly wrong, as it is not only a violation of the moral law, but has a great influence in encouraging inferior workmanship. In the case of a boiler which is blown out on Saturday, for the purpose of having it repaired on Sunday, every experienced mechanic knows that it is impossible to tell how long it will take to repair it until the work is actually accomplished, as it most generally happens that, as the work proceeds, unlooked for defects are discovered, or perhaps a different class of tools is required from those that were first intended. This necessitates delay, as it is well known that there are not the same opportunities for procuring the facilities for making a good job on Sunday as there are on other days, and as a result the work has to be hurried up, frequently botched, and in all probability left in a worse condition than before it was repaired. Men do less work on Sundays than on other days, being less energetic, more anxious to get through, and consequently more careless and inaccurate. The custom

of examining, testing, or repairing boilers on Sunday ought to be abandoned, condemned, and resisted by all concerned, as an unlawful, unnecessary, and mischievous practice.

NEGLECT OF STEAM-BOILERS.

Perhaps no appliances connected with factories, and other places, where power is used, are more sadly neglected than steam-boilers. This is a very surprising fact, when we consider the important part they occupy in the manufacturing arts. It would be difficult to assign any reasonable cause for this neglect, except that it may arise from the fact that nearly the whole attention of builders and leading engineers has been concentrated on the improvement and perfection of the steam-engine; and the practical engineer, following the example set by the leaders, generally devotes all his attention to it also.

In all cities, particularly in the business part of them, the use of steam-power is very general, and almost every square has its steam-boiler. In view of this fact, it behooves the merchants, capitalists, mechanics, and engineers, owning or in charge of boilers, to see that they are always cared for, and in as good order as they can be put. Experience has demonstrated the fact that very many boilers are not only sadly out of repair, but in many instances totally unfit to be used at the pressure at which they

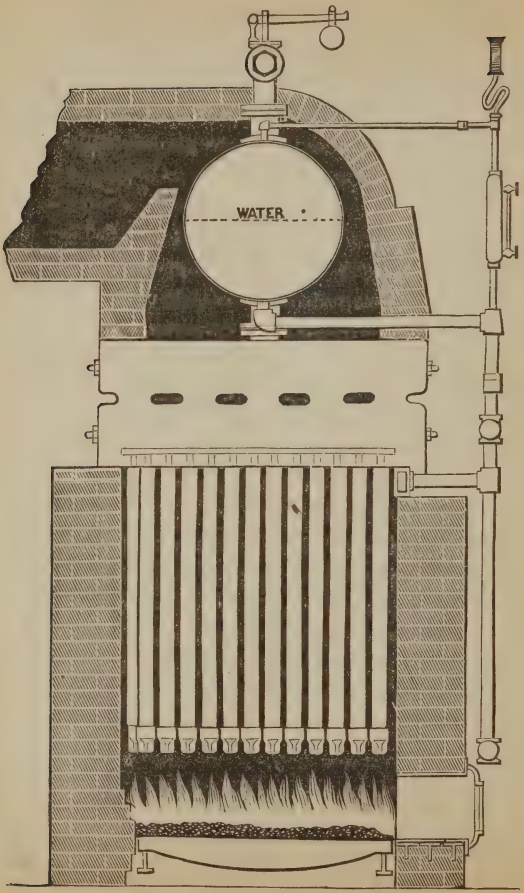
are worked; and it is also true that these boilers have become so by carelessness and neglect.

In the majority of cases, boilers are not cleaned half as often as they should be. When the water is hard, and scale accumulates on the sides or flues of the boiler, solvents are very often resorted to to remove the scale. After the scale has been thrown down it accumulates on the bottom of the boiler, and, if not removed at once, it becomes conglomerated, forms a heavy coating, and, if the boiler is externally fired, the bottom is liable to be burned through.

The annual reports of the Hartford Steam-Boiler Inspection and Insurance Company, year after year, show that nearly half of the whole number of defective boilers became so on account of incrustation and deposit of sediment; and, strange as it may seem, there are from thirty to forty per cent. more dangerous cases arising from the deposit of sediment than from incrustation and scale. The same reports further show that more than one-half the defective boilers from other causes are due to careless and incompetent management, proving clearly that a large number of cases from which explosions might be expected may be traced to a direct cause.

WIEGAND SECTIONAL BOILER.

The cut on page 112 represents the Wiegand Sectional Boiler. It is composed of a series of separable



THE WIEGAND SECTIONAL BOILER.

sections, of uniform size, placed side by side, and united to one feed-pipe and one steam-drum. Each section is composed of a double tank, five feet four inches in length, ten and a half inches wide, and twenty-four inches in height, twenty-four lap-welded, wrought-iron tubes, of three inches external diameter, with cast-iron cups, or caps, to close their lower ends, and a corresponding number of wrought-iron inner tubes, of one and three-quarter inches internal diameter.

The bottom of the tank has two rows of apertures, twelve in each row, into which the three-inch tubes are screwed. The tank is divided into two distinct compartments by a perforated diaphragm, placed a short distance above and parallel with the bottom. The diaphragm has two rows of apertures concentric with the apertures in the bottom of the tank, for the insertion of the one and three-quarter inch inner tubes. The cap, or cup, which closes the lower end of the three-inch tube is five inches in length, and is cast cylindrical at the part that screws upon the tube, below which it is shaped like a cone or funnel, with three channels extending from the base through its sides to the bottom of the cap, which is shaped like the trefoil.

Externally, the cap presents three equidistant wings, that afford a convenient means of applying a correspondingly-shaped wrench, to screw it on or off. Within each three-inch tube is placed a one and

three-quarter inch tube, that extends up through the apertures in the perforated diaphragm, in which it fits loosely. This arrangement permits an uninterrupted flow of water from the tank through the inner tubes into the caps; from thence upward through the annular spaces between the inner and outer tubes into the tank, and through the perforated diaphragm upward. These tanks are surmounted by a plain wrought-iron cylinder, thirty-six inches in diameter, and of such a length as to extend through the side walls enclosing the tanks, each tank being coupled thereto. This cylinder forms a part of the water-space, and all of the steam-space. The products of combustion encircle this cylinder. Water is supplied to, and blows off from, the section through the same orifice in the front end of the tank, and the steam passes from the top of the tank into the steam-cylinder. The furnace is a rectangular chamber, eight feet wide and four feet deep, with vertical walls, having the usual ash-pit, grate-bars, and fire-doors. The heat rises vertically between and around the tubes, also around the tanks and around the steam-drum, and is equally distributed.

The Wiegand Boiler has the reputation of being an efficient steamer, and is claimed to be non-explosive; but, like all the rest of the sectional boilers, little or nothing is known of its durability and economy.

SAFE WORKING PRESSURE OF STEAM-BOILERS.

Rule *for finding Safe Working Pressure of Steel Boilers.*—Multiply thickness of steel by .56 if single-riveted, and .70 if double-riveted; multiply this product by 16,000 (safe load); then divide this last product by the external radius (less thickness of steel); the quotient will be the safe working pressure in pounds per square inch.

For iron boilers, multiply the thickness of iron by .56 if single-riveted, and .70 if double-riveted; multiply this product by 10,000 (safe load); then divide this last product by the external radius (less thickness of iron); the quotient will be the safe working pressure in pounds per square inch.

EXAMPLE.

Diameter of boiler .....42 inches.
Thickness of iron ..... $\frac{3}{8}$ "

2)42

21 external radius.

.375

20.625 internal radius.

Thickness of iron $\frac{3}{8} = .375$

.56 single-riveted.

2250

1875

.21000

10000 safe load.

20.625)210000000 [pressure.

101.81 pounds safe working

In the foregoing rule, 50,000 pounds per square inch is taken as the tensile strength of boiler-iron, and one-fifth of that, or 10,000, as the safe load. Hence five times the safe working pressure, or 50,000 pounds, would be the bursting pressure. The ultimate strength and safe working strength of boiler-plate of every thickness are well understood by intelligent mechanics, as eminent engineers in this country and in other countries have made the subject of iron under different circumstances a study; they have tested its strength under different degrees of heat; * they have tested it when riveted, in order to ascertain what resistance it has to withstand tensile strain; they have tested it in relation to its quality, and from these experiments certain data are obtained, on which calculations are founded, the results of which, in practice, are not only reckless, but criminal to disregard.

To ascertain the strain per square inch of sectional area to which boilers are subjected under working pressures, we must know the diameter of the boiler, the thickness of the iron of which it is constructed, and the pressure per square inch of steam as shown on the gauge; then by multiplying the surface of the plate required for one square inch of sectional area by the pressure of steam in pounds, multiplying result by the diameter of the boiler in inches, and dividing by 2, we get the strain per square inch of

* See Tables on pages 326, 327.

sectional area to which the boiler is subjected. The surface of boiler-plate required for one square inch of sectional area will depend upon the thickness of plate; thus, iron $\frac{1}{4}$ inch thick will require 4 superficial inches to make one square inch of sectional area; iron $\frac{1}{2}$ inch thick will require 2; iron $\frac{3}{8}$ inch thick will require 2.66, and so on.

Rule for finding the Pressure per square inch of Sectional Area on the Crown-Sheets of Steam-Boilers.

Multiply the width of the crown-sheet in inches by its length in inches; multiply this product by the pressure of the steam in pounds per square inch by the gauge.

EXAMPLE.

Length of crown-sheet..... 48 inches.
Width of crown-sheet..... 36 inches.

36
48
288
144
1728
Pressure per sq. in. 80 lbs.
2)138240
2000)69120 lbs.
34.560 tons.

Rule for finding the Aggregate Strain caused by the Pressure of Steam on the Shells of Boilers.

Multiply the circumference in inches by the length in inches; multiply that product by the pressure in pounds per square inch. The result will be the aggregate pressure on the shell of the boiler.

EXAMPLE.

Diameter of boiler.....	42 inches.
Circumference of boiler.....	131.9472 "
Length of boiler.....	10 feet, or 120 "
Pressure of boiler.....	125 lbs.

$$\frac{131.9472 \times 120 \times 125}{2000} = 1{,}979{,}208 \text{ pounds, or } 989 \text{ tons.}$$

EXPLANATION OF THE FOLLOWING TABLES.

The horizontal column on top of the page, $\frac{3}{8}$, 00, 0, 1, etc., represents the number of the iron or steel.

The decimals, in the second horizontal column, are equal to the fractional parts of an inch in the third.

The vertical column on the left hand side is the diameters of the boilers in inches. All the other columns represent pounds.

Example. — 24-inch diameter, $\frac{3}{8}$ steel, 289.03 pounds per square inch.

Example. — 40-inch diameter, $\frac{3}{8}$ iron, 107.01 pounds per square inch.

TABLE

OF SAFE INTERNAL PRESSURES FOR STEEL BOILERS.

Birmingham Wire Gauge.		3/8	00	0	1	2
Thickness of Steel.		.375 3/8	.358 3/8 Scant.	.340 11/32	.300 5/16	.284 9/32
	In.	lbs. per sq. in.				
External Diameter.	24	289.03	275.52	261.26	229.74	217.19
	26	266.13	253.73	240.31	211.65	200.08
	28	246.66	235.13	223.01	196.20	185.45
	30	229.74	219.00	207.80	182.85	172.99
	32	215.04	205.06	194.15	171.21	161.91
	34	202.10	192.74	182.85	160.95	152.22
	36	190.63	181.82	172.50	151.86	143.23
Longitudinal Seams, Single Riveted.	38	180.40	172.06	163.25	143.74	135.96
	40	171.21	163.30	154.95	136.44	129.06
	42	162.90	155.39	147.45	129.85	122.83
	44	155.37	148.21	140.66	123.87	117.17
	46	148.50	141.66	134.43	118.41	112.01
	48	142.22	135.67	128.75	113.41	107.29
	50	136.44	130.17	123.53	108.82	100.03
	52	131.12	125.09	118.72	104.59	98.95
	54	126.19	120.39	114.26	100.67	95.24
	56	121.62	116.04	110.13	97.03	91.81
	58	117.37	111.99	106.29	93.65	88.61
	60	113.41	108.21	102.71	90.50	85.63
	62	109.71	104.68	99.36	87.55	82.89
	64	106.24	101.37	96.22	84.79	80.23
	66	102.98	98.26	93.27	82.20	77.77
	68	99.92	95.34	90.32	79.76	75.47
	70	97.03	92.59	87.89	77.43	73.29
	72	94.31	89.99	85.42	75.29	71.24
	74	91.74	87.81	83.09	73.24	69.30
	76	89.30	85.21	80.89	71.29	67.46
	78	86.99	83.01	78.79	69.45	65.72
	80	84.79	80.91	76.81	67.70	64.07

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR STEEL BOILERS.

Birmingham Wire Gauge.		3	4	5	6	7	8
Thickness of Steel.		.259 $\frac{1}{4}$ Full.	.238 $\frac{1}{4}$ Scant	.220 $\frac{7}{32}$	.203 $\frac{6}{32}$ Full	.180 $\frac{6}{32}$ Sc't.	.165 $\frac{5}{32}$ Full
	In	lbs. per sq. in.					
External Diameter.	24	197.63	181.13	167.33	154.18	136.44	124.91
	26	182.13	167.09	154.24	142.13	125.80	115.10
	28	168.88	154.95	143.04	131.83	116.70	106.85
	30	157.42	144.45	133.36	122.92	108.82	99.65
	32	147.42	135.29	124.91	115.14	101.94	93.36
	34	138.60	127.22	117.47	108.28	95.88	87.81
Long. Seams, Single Riveted.	36	130.80	120.05	110.86	102.20	90.50	82.89
	38	123.82	113.65	104.96	96.76	85.69	78.49
	40	117.55	107.90	99.65	91.81	81.37	74.53
	42	111.40	102.71	94.85	87.45	77.46	70.95
	44	106.71	97.99	90.50	83.44	73.91	67.70
	46	102.04	93.68	86.53	79.78	70.67	64.74
	48	97.74	89.74	82.89	76.43	67.70	62.02
	50	93.07	86.11	79.54	73.35	64.97	59.12
	52	90.15	82.77	76.46	70.50	62.45	57.22
	54	86.78	79.68	73.60	67.87	60.13	55.09
	56	83.65	76.09	70.95	65.43	57.97	53.11
	58	80.74	74.14	68.49	63.16	55.96	51.27
	60	78.02	71.62	66.19	61.07	54.04	49.55
	62	75.49	69.32	64.04	59.06	52.32	47.94
	64	73.11	67.13	62.02	57.20	50.68	46.43
	66	70.88	65.09	60.13	55.45	49.14	45.02
	68	68.77	63.16	58.35	53.52	47.68	43.69
	70	66.79	61.28	56.67	52.27	46.31	42.44
	72	64.92	59.76	55.09	50.81	45.02	41.25
	74	63.16	58.00	53.59	49.43	43.80	40.13
	76	61.48	56.47	52.17	48.12	42.64	39.07
	78	59.90	55.01	50.83	46.88	41.54	38.06
	80	58.39	53.63	49.55	45.65	40.50	37.11

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR STEEL BOILERS.

Birmingham Wire Gauge.		$\frac{3}{8}$	00	0	1	2
Thickness of Steel.		.375 $\frac{3}{8}$	.358 $\frac{3}{8}$ Scant.	.340 $\frac{11}{32}$	.300 $\frac{5}{16}$	.284 $\frac{9}{32}$
	In.	lbs. per sq. in.				
External Diameter.	24	361.29	344.40	326.58	287.23	271.49
	26	332.67	317.24	300.78	264.56	250.14
	28	308.25	293.91	278.77	237.95	231.90
	30	287.18	273.48	259.75	228.57	216.14
	32	268.80	256.34	243.16	214.01	202.39
Longitudinal Seams, Double Riveted.	34	252.63	240.93	228.57	201.19	190.28
	36	238.24	227.27	215.62	189.83	179.54
	38	225.50	215.08	204.07	179.67	169.95
	40	214.01	204.13	193.69	170.55	161.28
Curvilinear Seams, Single Riveted.	42	203.63	194.24	184 31	162.31	153.54
	44	194.21	185.26	175.80	154.83	146.47
	46	181.21	177.08	168.04	148.01	140.02
	48	177.77	169.55	160.94	141.77	134.12
	50	170.55	162.71	154.41	136.03	128.69
	52	163.90	156.40	148.01	130.73	123.68
	54	157.74	150.49	142.83	125.84	119.05
	56	152.03	145.05	137.61	121.29	114.76
	58	146.72	139.99	132.86	117.01	110.76
	60	141.77	135.26	128.38	113.13	107.03
	62	137.14	130.85	124.20	109.44	103.55
	64	132.80	126.74	120.27	105.99	100.29
	66	128.73	122.83	116.53	102.75	97.22
	68	124.90	119.18	113.13	99.70	94.34
	70	121.29	115.74	109.86	96.85	91.62
	72	117.89	112.49	106.78	94.11	89.05
	74	114.67	109.42	103.87	91.55	86.63
	76	111.62	106.51	101.11	89.12	84.33
	78	108.73	103.76	98.49	86.72	82.15
	80	105.99	101.14	96.01	84.63	80.08

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR STEEL BOILERS.

Birmingham Wire Gauge.		3	4	5	6	7	8
Thickness of Steel.		.259 $\frac{1}{4}$ Full.	.238 $\frac{1}{4}$ Scant	.220 $\frac{7}{32}$	.203 $\frac{6}{32}$ Full	.180 $\frac{6}{32}$ Sc't.	.165 $\frac{5}{32}$ Full
	In.	lbs. per sq. in.					
External Diameter.	24	247.06	226.62	209.16	192.72	175.63	156.14
	26	227.67	208.87	192.80	177.66	157.25	143.98
	28	211.10	193.69	178.80	164.78	145.87	133.57
	30	196.78	180.57	166.71	153.65	136.03	124.57
	32	184.28	169.75	156.14	143.92	127.43	116.70
Long. Seams, Double Riveted. Curvil. Seams, Single Riveted.	34	173.27	159.06	146.84	135.35	119.85	109.77
	36	163.50	150.07	138.58	127.75	113.13	103.61
	38	154.73	142.07	131.20	120.95	107.12	98.11
	40	146.94	134.88	124.57	114.84	101.71	93.16
	42	139.85	128.38	118.57	109.32	96.82	88.69
	44	133.42	122.48	113.13	104.30	92.39	84.64
	46	127.55	117.10	108.16	99.73	88.34	80.92
	48	122.18	112.17	103.61	95.54	84.63	77.53
	50	117.24	107.64	99.43	91.68	81.22	74.41
	52	112.69	103.43	95.53	88.13	78.07	71.53
	54	108.47	99.60	92.00	84.84	75.16	68.86
	56	104.56	96.01	88.69	81.79	72.46	66.39
	58	100.92	92.67	85.61	78.95	69.95	64.08
	60	97.53	89.56	22.74	76.26	67.60	61.60
	62	94.36	86.65	80.11	73.17	65.44	59.93
	64	91.38	83.98	77.53	71.52	63.35	58.04
	66	88.59	81.36	75.16	69.32	61.42	56.28
	68	85.97	78.95	72.94	67.23	59.60	54.61
	70	83.49	76.68	70.84	65.34	57.89	53.05
	72	81.16	74.53	68.86	63.51	56.28	51.56
	74	78.95	72.50	66.72	61.78	54.75	50.16
	76	76.86	70 58	65.21	60.15	53.30	48.84
	78	74.87	68.76	63.52	58.60	51.93	47.58
	80	72.99	66.96	61.94	57.12	50.62	46.39

TABLE

OF SAFE INTERNAL PRESSURES FOR IRON BOILERS.

Birmingham Wire Gauge.		$\frac{3}{8}$	00	0	1	2
Thickness of Iron.		.375 $\frac{3}{8}$	.358 $\frac{3}{8}$ Scant.	.340 $\frac{11}{32}$	.300 $\frac{5}{16}$	.284 $\frac{9}{32}$
	in.					
External Diameter.	24	180.65	172.20	163.29	143.59	135.75
	26	166.34	158.58	150.39	132.28	125.08
	28	154.13	146.96	139.38	122.63	115.95
	30	143.59	136.92	129.88	114.29	108.07
	32	134.40	128.17	121.58	107.01	101.20
	34	126.31	120.47	114.29	100.60	95.14
	36	119.15	113.64	107.81	94.92	89.77
Longitudinal Seams, Single Riveted.	38	112.75	107.54	102.04	89.84	84.98
	40	107.01	102.07	96.85	85.28	80.67
	42	101.81	97.12	92.11	81.16	76.77
	44	97.11	92.63	87.90	77.42	73.24
	46	92.82	88.54	84.02	74.01	70.01
	48	88.89	84.80	80.47	70.89	67.06
	50	85.28	81.36	77.21	68.02	64.35
	52	81.95	78.18	74.20	65.37	61.84
	54	78.87	75.25	71.42	62.92	59.53
	56	76.02	72.53	68.84	60.65	57.38
	58	73.36	70.00	66.43	58.54	55.38
	60	70.89	67.63	64.19	56.57	53.52
	62	68.57	65.43	62.10	54.72	51.78
	64	66.40	63.36	60.14	53.00	50.15
	66	64.37	61.42	58.30	51.38	48.61
	68	62.45	59.59	56.57	49.85	47.17
	70	60.65	57.87	54.93	48.41	45.81
	72	58.95	56.25	53.39	47.06	44.53
	74	57.34	54.71	51.94	45.78	43.32
	76	55.81	53.26	50.56	44.56	42.17
	78	54.37	51.88	49.25	43.41	41.08
	80	53.00	50.57	48.01	42.32	40.04

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR IRON BOILERS.

Birmingham Wire Gauge.		3	4	5	6	7	8
Thickness of Iron.		.259 $\frac{1}{4}$ Full.	.238 $\frac{1}{4}$ Scant.	.220 $\frac{7}{32}$	.203 $\frac{6}{29}$ Full.	.180 $\frac{6}{32}$ Sc't.	.165 $\frac{5}{32}$ Full.
	In.						
External	24	123.53	113.31	104.58	96.36	85.28	78.07
Diameter	26	113.84	104.44	96.40	88.83	78.63	71.99
	28	105.55	96.85	89.40	82.39	72.94	66.79
	30	98.39	90.29	83.36	76.83	68.02	62.29
	32	92.14	84.56	78.07	71.96	63.72	58.35
	34	86.64	79.51	73.42	67.68	59.93	54.89
	36	81.75	75.04	69.29	63.88	56.57	51.81
Long.	38	77.39	71.04	65.60	60.48	53.56	49.06
Seams.	40	73.47	67.44	62.29	57.42	50.86	46.58
Single	42	69.93	64.19	59.29	54.66	48.41	44.35
Riveted.	44	66.71	61.24	56.57	52.15	46.20	42.32
	46	63.78	58.55	54.08	49.87	44.17	40.46
	48	61.09	56.09	51.81	47.77	42.32	38.77
	50	58.62	53.82	49.72	45.84	40.61	37.21
	52	56.35	51.74	47.79	44.07	39.04	35.77
	54	54.24	49.80	46.00	42.42	37.58	34.43
	56	52.28	48.01	44.35	40.90	36.23	33.20
	58	50.46	46.34	42.81	39.48	34.98	32.04
	60	48.77	44.78	41.37	38.15	33.80	30.97
	62	47.18	43.33	40.03	36.91	32.71	29.97
	64	45.69	41.96	38.77	35.75	31.68	29.02
	66	44.30	40.68	37.58	34.66	30.71	28.14
	68	42.99	39.48	36.47	33.64	29.80	27.31
	70	41.75	38.34	35.42	32.67	28.95	26.53
	72	40.58	37.27	34.43	31.76	28.14	25.78
	74	39.48	36.25	33.50	30.89	27.38	25.08
	76	38.43	35.29	32.61	30.08	26.65	24.42
	78	37.44	34.38	31.77	29.30	25.96	23.79
	80	36.49	33.52	30.97	28.56	25.31	23.20

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR IRON BOILERS.

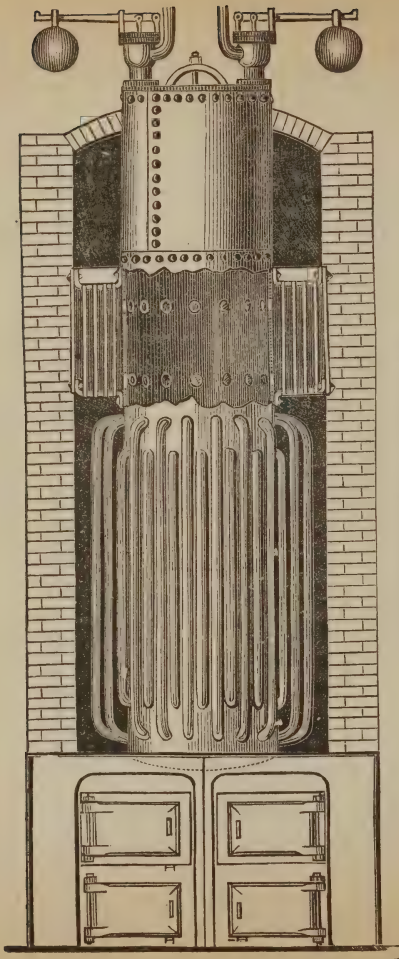
Birmingham Wire Gauge.		$\frac{3}{8}$	00	0	1	2
Thickness of Iron.		.375 $\frac{3}{8}$	.358 $\frac{3}{8}$ Scant.	.340 $\frac{11}{32}$	.300 $\frac{5}{16}$	.284 $\frac{9}{32}$
	In.					
External	24	225.81	215.26	204.12	179.49	169.67
Diameter.	26	207.93	198.23	187.91	165.35	156.34
	28	192.66	183.70	174.23	153.28	144.94
	30	179.19	171.15	162.35	142.86	135.09
	32	168.00	160.21	151.98	133.76	126.49
Longitudinal	34	157.89	150.58	142.86	125.75	118.93
Seams,	36	148.94	142.05	134.77	118.64	112.21
Double	38	140.94	134.43	127.55	112.30	106.22
Riveted.	40	133.76	127.58	121.06	106.60	100.83
Curvilinear	42	127.27	121.40	115.20	101.45	95.96
Seams,	44	121.39	115.79	109.88	96.77	91.55
Single	46	116.02	110.68	105.03	92.51	87.52
Riveted.	48	111.11	106.00	100.59	88.61	83.83
	50	106.19	101.70	96.51	85.02	80.43
	52	102.44	97.73	92 75	81.71	77.31
	54	98.59	94.10	89.27	78.69	74.41
	56	95.02	90.66	86.04	75.81	71.73
	58	91.70	87.49	83.04	73.17	69.23
	60	88.61	84.54	80.24	70.71	66.90
	62	85.71	81.78	77.63	68.40	64.72
	64	83.00	79.17	75.17	66.25	62.68
	66	80.46	76.78	72.87	64.22	60.77
	68	78.07	74.49	70.71	62.31	58.96
	70	75.81	72.34	68.67	60.52	57.26
	72	73.68	70.31	66.74	58.82	55.66
	74	71.67	68.39	64.92	57.22	54.15
	76	69.77	66.60	63.19	55.70	52.71
	78	67.96	64.85	61.56	54.26	51.35
	80	66.25	63.22	60.01	52.90	50.06

TABLE—(*Continued*)

OF SAFE INTERNAL PRESSURES FOR IRON BOILERS.

Birmingham Wire Gauge.		3	4	5	6	7	8
Thickness of Iron.		.259 $\frac{1}{4}$ Full.	.238 $\frac{1}{4}$ Scant.	.220 $3\frac{7}{2}$	.203 $3\frac{6}{2}$ Full.	.180 $3\frac{6}{2}$ Scant.	.165 $3\frac{5}{2}$ Full.
	In.						
Ext'l	24	154.42	141.64	130.73	120.45	106.60	97.59
Diam.	26	142.30	130.54	120.50	111.04	98.21	89.99
	28	131.94	121.06	111.76	102.99	91.17	83.48
	30	122.99	112.86	104.19	96.03	85.02	77.86
	32	116.32	105.70	97.59	89.95	79.65	72.94
Long.	34	108.30	99.39	91.78	84.60	74.91	68.61
Seams,	36	102.19	93.80	86.61	79.84	70.71	64.76
Doub'e	38	96.74	88.80	82.00	75.60	66.95	61.32
Riv't'd	40	91.84	84.30	77.86	71.78	63.57	58.23
Curvil.	42	87.41	80.24	74.11	68.33	60.52	55.44
Seams,	44	83.39	76.56	70.71	65.19	57.75	52.90
Single	46	79.72	73.19	67.60	62.33	55.22	50.58
Riv't'd	48	76.37	70.11	64.76	59.71	52.90	48.46
	50	73.28	67.28	62.11	57.31	50.77	46.51
	52	70.43	64.67	59.74	55.08	48.80	44.71
	54	67.80	62.25	57.51	53.40	46.98	43.04
	56	65.35	60.01	55.44	51.12	45.29	41.50
	58	63.07	57.92	53.51	49.35	43.72	40.06
	60	60.96	55.98	51.71	47.69	42.25	38.71
	62	58.98	54.16	50.03	46.14	40.88	37.46
	64	57.12	52.45	48.46	44.69	39.60	36.28
	66	55.37	50.85	46.98	43.33	38.39	35.18
	68	53.73	49.35	45.59	42.05	37.26	34.14
	70	52.19	47.93	44.28	40.84	36.19	33.16
	72	50.73	46.59	43.04	39.70	35.18	32.23
	74	49.35	45.32	41.87	38.62	34.22	31.36
	76	48.04	44.11	40.76	37.60	33.32	30.53
	78	46.80	42.98	39.71	36.63	32.46	29.74
	80	45.62	41.90	38.71	35.71	31.64	28.99

THE importance of a correct Safety-valve can hardly be over-estimated, and it is the duty of every man owning a Steam-boiler to see that this important adjunct is well proportioned and always in good condition. The Safety-valve should only be regarded as a means of safety when well proportioned, well constructed, and well cared for after being put in use.



THE ROGER'S AND BLACK BOILER.

THE ROGER'S AND BLACK BOILER.

The cut on opposite page represents the Roger's and Black Boiler. It consists of a cylindrical shell, suspended vertically by four wrought-iron brackets or knees, placed equidistant near the top of the shell, which rests upon the brick casing of the boiler. The shell is invested with two lengths of external circulating tubes of two inches diameter. The products of combustion pass up the outside of the shell around the outside tubes, thence up through the tubes in the drum to the upper part of the outside shell to the stack. This boiler possesses no advantages over any of the ordinary forms of wrought-iron boilers except in compactness and economy of space. It has the disadvantage of a large shell and convex crown-sheet directly over the fire, which forms a receptacle for all the deposits in the feed-water, rendering it liable to be over-heated or burned through. The cylindrical shell is considerably weakened in consequence of the perforations to receive the tubes.

SELECTION OF STEAM-BOILERS.

Every boiler should be selected with a view to meet the particular purpose for which it is to be employed, and all the circumstances connected with its use, such as location, pressure, character of the

water, quality of the fuel, &c., should be duly considered. Some boilers should have small steam and water room, and at the same time possess great strength and be capable of generating steam very rapidly; while in others the reverse of these conditions is more desirable. In cases where fuel is abundant and of little value, the character of the boiler makes very little difference, provided it possess sufficient strength and afford ample facilities for cleaning, repairs, or renewal of any of its parts; while on the other hand, in locations where fuel is scarce, the boiler that will give the most economical results with the smallest quantity of fuel is the most desirable.

There are thousands of boilers put in use every year totally unfit for the location and purposes for which they are employed, that would answer very well under other circumstances. There are also thousands of boilers now in use that possess poor steaming qualities, and on account of defects of design are weak and dangerous, and not at all durable, as they afford no opportunity for cleaning or repairs, while others require special tools to repair them, thereby incurring loss both in expense and time. Such boilers must ever have a narrow limit of usefulness; while those possessing strength, simplicity of design and construction, capable of being managed with ordinary care, affording the best facilities for cleaning and repairing, offering the most resistance to the destructive effects of the chemicals both in the

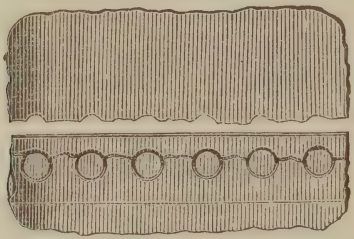
water and fuel, and being capable of being set up almost any place and used under almost every circumstance, must ever have the widest field of usefulness and be the most reliable and satisfactory to steam-users. For this reason there is not a shade of doubt that the old-fashioned wrought-iron cylinder, flue, and tubular boilers will ever be superseded by any others.

PULSATION IN STEAM-BOILERS.

Pulsation in steam-boilers, though not discernible to the eye, as in animated nature, goes on intermittently in some boilers whenever they are in use. It is induced by weakness and want of capacity in the boiler to supply the necessary quantity of steam, and sometimes is caused by the boiler being badly designed, thereby admitting of a great disproportion between the heating-surface and steam-room. Boilers are frequently found in factories that were originally not more than of sufficient capacity to furnish the necessary quantity of steam, but, as business increased, it became necessary to increase the pressure, and also the speed of the engine, or, perhaps, to replace it with a larger one, which has to be supplied with steam from the same boiler. The result is, each time the valve opens to admit steam to the cylinder, about one-third of the whole quantity in the boiler is admitted, thus lowering the pressure; the next instant, under the influence of

hard firing, or, perhaps, a forced draught, the steam is brought to the former pressure, and so on; this lessening and increasing the pressure continues while the engine is in motion, which has an effect on the boiler similar to the breathing of an animal.

The strains induced by this pulsation are transmitted to the weakest places, viz., the line of the rivet-holes, and that marked by the tool in the process of calking; the result is, the plate is broken in two, as shown in the following cut. The manner in which the break takes place may be illustrated by filing a small nick, or drilling a small hole, in a



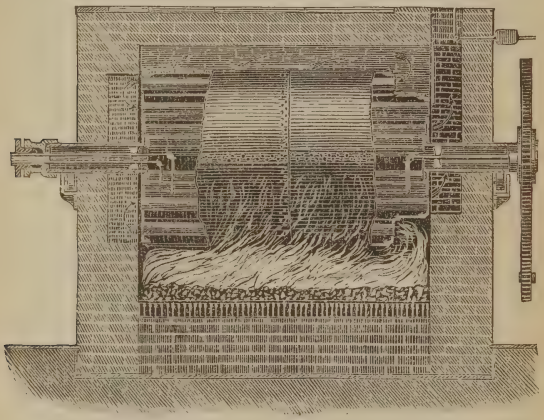
piece of hoop or band-iron, and then bending back and forth, when it will be discovered that the material will break just at that point, however slight the nick or small the hole may be. Pulsation is frequently very severe in the boilers of tug-boats when commencing to start a heavy tow, and also in locomotives when starting long trains. Some frightful

explosions of the boilers of tug-boats and locomotives have occurred under such circumstances. Pulsation, if permitted to continue, is sure to effect the destruction of the boiler. It is always made manifest by the vibrations of the pointers on steam-gauges, or an unsteadiness in the mercury column. It may be remedied, to a certain extent, by adding a larger steam-dome, but this has a tendency to weaken the boiler, and render it more unsafe. The only sure preventive of such a silent and destructive agent is to have the boiler of sufficient capacity in the first place.

PIERCE'S ROTARY TUBULAR BOILER.

This boiler is entirely encased in brickwork, and is supported upon trunnions at each end, in such a manner that it is rotated by a gear, actuated by the steam-pump, which supplies the boiler with water, or other motor power. The boiler is, at all times, one-quarter full of water, which amount is unchangeable, being regulated by an automatic feed-water regulator. The feed-water is introduced through one trunnion, and the steam withdrawn through the opposite one. The grate has an area equal to the entire inner base of the brickwork surrounding the boiler. The flame and heated gases arising from the grate completely surround the boiler, thence pass through the outer row of tubes

to the opposite end, and emerge into a chamber, thence returning through the inner or superheating row of tubes, *en route* to the stack or chimney. The constant and thorough circulation of the water, it is claimed, facilitates an easy escape of the steam, and prevents foaming, while the passage of the steam



PIERCE'S ROTARY TUBULAR BOILER.

over and among the superheating tubes raises its temperature sufficiently to allow of considerable expansion; nevertheless there is some exaggeration in this respect, as it is difficult to see what advantage can be gained by such an arrangement. In the first place, it is complicated, and expensive to build; besides, it requires power to work it, and, as

the mud and deposit are kept in continual agitation, it has a tendency to pass over with the steam, and destroy the piston, cylinder, valve-faces, and seats.

LOCATION OF STEAM-BOILERS.

No class of machines are oftener injudiciously located, or show by their location a greater disregard for the convenience and comfort of those who tend them than steam-boilers. It is quite common to find boilers stowed away in dark, damp, and out-of-the-way places, although there may be an abundance of unoccupied room in the same establishment; and also to find boilers so situated that it is utterly impossible to examine or repair them, and very difficult and laborious to fire them. Even in many instances where boilers are located in light and airy places, they are sunk several feet below the surface of the ground on which they ought to stand, although there may be thousands of cubic feet of unoccupied space above them. Such ignorance and recklessness can only be accounted for by the fact that for years an idea has generally prevailed among owners of steam-boilers that any location or out-of-the-way place was good enough for a steam-boiler, and that any kind of care, after it was located, was sufficient to manage it.

In one instance in Philadelphia the proprietor of a factory located his boiler in a passageway of about four feet between two buildings, and walled it in

front and rear, covering the top with iron girders and heavy flagging stones. Although the engineer was there seven years, he never cleaned the flues, as there was no arrangement made for doing so when the boiler was set. He never saw the safety-valve, and when asked if he knew where it was, said, "he supposed it was up under them flags, as he heard a hissing and snorting up there sometimes."

In another instance, the owner of a steam-boiler placed it in a coal vault, under a sidewalk, and walled it in between solid masonry. After it had been two years in use he was asked if he had a good safety-valve on his boiler, and he answered that he did not know, as he never saw it; and when asked if he knew whether there was any at all or not, he answered no. He remembered that the man who built his boiler asked him if he wanted a safety-valve, and he told him that he did. Some day he would try to find out, and if there was not any on he would make the boiler-maker return the price of the safety-valve.

In another case in a hotel, where there was a large roomy basement 40×60 feet, and very high between the floor and the ceiling, the boiler was placed in a hole in one corner, five feet below the level of the floor. The fire-room was made 3×4 feet, and when the engineer or fireman cleaned or replenished his fire he had to stand on perhaps a ton of coal in that hole. On one occasion, when a cap blew off one of the steam-pipes, the engineer, in

attempting to escape, was scalded to death, which was caused by an old ladder that was used for ascending and descending into the hole breaking under him.

Another case occurred in a large safe factory. The boiler was placed crosswise in the cellar, and was just three feet shorter than the building and about four feet below the level of the floor. The engine then was set directly against the side of the boiler, and when the engineer stopped or started his engine he had to go up two or three steps and stand on top of the boiler. The flues of the boiler were only cleaned twice in ten years.

Another instance was that of a planing-mill, where four cylinder boilers were buried in the ground in the yard, without any shed over them, so that the top of the brickwork extended about one foot above the surface of the ground. The top of the boilers was a receptacle for all kinds of refuse material, and finally the keeper of a large livery stable next door commenced to pile his horse-manure on top of the boilers, the owner of which thought it was a very good arrangement, as the heat arising from the manure would be apt to make a great saving in fuel for him in the course of the year.

Another instance was where four large flue boilers were placed in a basement between four solid walls, and the top covered over with brick arches, resting on iron girders, not more than fifteen inches above the shells of the boilers. The coal was run down

into the fire-room through a circular hole, twenty inches in diameter, and the ashes had to be lifted through the same hole in an ordinary water-bucket attached to a rope. In this case there was a fine yard directly over the boilers that was only occupied by old barrel hoops and broken package boxes.

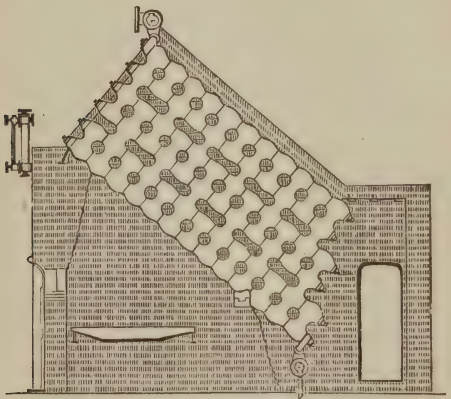
Another was the case of a boiler in a glass factory, which was sunk in the ground four feet below the level of the water in the creek on which the works were located. Every time the engine was stopped the water flowed in, filling the boiler-room, putting out the fire, and sometimes submerging the boiler, and although an intelligent bricklayer offered to remedy the difficulty for twelve dollars, the proprietor declined. He preferred to pay twenty-five dollars for a bilge-pump to pump out the water by hand every morning before the engine was started.

Such blunders as these might be enumerated sufficiently to make a good-sized volume, but it is unnecessary, as the foregoing will be sufficient to show the unpardonable errors that were made in connection with steam-boiler engineering.

THE HARRISON BOILER.

This boiler consists of sections or hollow cast-iron grooves, connected together, and communicating freely with each other. This form combines the greatest strength with the least weight of material;

but the capacity of the spheres is so limited that they soon become choked with deposit, which induces leakage, and necessitates their renewal. It may be said to be more safe from explosion than



THE HARRISON SECTIONAL BOILER.

any other sectional boiler in use; but it is unfit to stand hard firing, or where it has to be taxed to its utmost capacity. It is better adapted to the purpose of heating buildings, or where a very low pressure will answer.

BOILER-FLUES.

The well-established law that the strength of cylinders is inversely as their diameters, and the hitherto undisputed axiom among practical engi-

neers, that cylindrical tubes or boiler-flues, when subjected to uniform external pressure, were equally strong in every part, regardless of length, led to erroneous opinions regarding the strength of boiler-flues. For flues to collapse, under the ordinary working pressure of steam in what was supposed to be properly-proportioned and well-made boilers, was formerly not an unusual occurrence; and, although many theories were advanced on the subject, it was not until the celebrated English engineer, William Fairbairn, made an extensive set of experiments on the strength of tubes of various diameters, lengths, and thicknesses of material, that the real cause of the weakness of boiler-flues was revealed.

These experiments were made by hydrostatic pressure, applied both externally and internally, to test the strength under ordinary conditions of practice, and they proved conclusively that the strength of flues exposed to external pressure, as ordinarily used, is inversely as the length; that is, a flue twenty feet long will collapse with just half the pressure of a flue ten feet long, everything else being equal; in other words, a flue twenty feet long, which would bear a pressure of ninety pounds per square inch, if shortened to ten feet, or, what is the same thing in effect, if it be hooped in the middle of its length by T-iron, will then bear a much higher pressure. Although it had long been established that a circle is the strongest possible form that can be made, and

that no deviation from it can be made without reduction of strength, yet it was not previously known that a nine-inch diameter of tube was reduced in strength more than one-third by deviating from the shape of a circle only sufficient to make a lap-joint, the ratio being as seven to ten, so proved by actual tests.

When pressure is exerted within a tube or cylinder, with spherical ends, the tube can only give way by the metal being torn asunder; and the tendency of the strain is to cause the tube to assume the true cylindrical figure, or spherical form,—the form of greatest resistance. With pressure exerted on the outside of a tube, the tendency of that pressure is to crush in the tube—to flatten it. It is well known that iron of any strength, when formed into a tube, will bear a much greater strain to tear it asunder, if that pressure be applied *internally*, than it will bear without crushing in when applied *externally*. A bar of iron, when used as a *tie-rod*, will resist a very large amount of tearing force; but that same bar, placed as a prop only, under the weight exerted in the former case, would be doubled up and crushed out of form. The inner tubes of boilers are nothing more nor less than a series of props, as they have to sustain the immense weight of the pressure exerted externally on their diameter. The constant and never-ceasing tendency is for those props to give way — for the cylindrical tube to depart from the

form of greatest resistance, to become flattened or bulged, and ultimately crushed in. The foregoing conclusions show the imperative necessity of adhering to the true circle for boiler-flues, more especially where high-pressure steam is used.

Rule *for finding the Safe External Pressure on Boiler-Flues.*— Multiply the square of the thickness of the iron by the constant whole number, 806,300; divide this product by the diameter of the flues in inches; divide the quotient by the length of the flue in feet; divide this quotient by 3. The result will be the safe working pressure.

EXAMPLE.

Diameter, 13 inches. Length, 10 feet.

Thickness, $\frac{3}{8}$ of an inch.

$\frac{3}{8} \times \frac{3}{8} = \frac{9}{64}$.

13 diameter.
10 length.
130
3
390

$\frac{9}{64} \times 806{,}300 = \frac{7256700}{64} \div 390 = \frac{7256700}{24960} = 290.73$ safe external pressure.

TABLE

OF SQUARES OF THICKNESSES OF IRON, AND CONSTANT NUMBERS TO BE USED IN FINDING THE SAFE EXTERNAL PRESSURE FOR BOILER FLUES.

Birmingham Gauge.				
$\frac{3}{8}$	.375	.375	806,300	113,385.937500
00	.358	.358	806,300	103,338.633200
0	.340	.340	806,300	93,208.280000
1	.300	.300	806,300	72,567.000000
2	.284	.284	806,300	65,032.932800
3	.259	.259	806,300	54,087.410300
4	.238	.238	806,300	45,672.057200
5	.220	.220	806,300	39,024.920000
6	.203	.203	806,300	33,226.816700
7	.180	.180	806,300	26,124.120000
8	.165	.165	806,300	21,951.517500

Explanation.— The column on the left-hand side of the page, $\frac{3}{8}$, 00, 0, 1, etc., represents the number of the boiler iron according to the Birmingham wire gauge; the second and third columns, .375, .358, etc., represent the decimal parts of an inch, the inch being taken as 10,000, which columns being multiplied together give the square of the thickness of the iron; the fourth column represents the constant number 806,300, by which we multiply the several squares of the thicknesses; the fifth column represents the several products.

TABLE

OF SAFE WORKING EXTERNAL PRESSURES ON FLUES 10 FEET LONG.

BIRMINGHAM GAUGE.	3/8	00	0	1	2
Thickness of Iron.	.375	.358	.340	.300	.284
Diam. in In.					
6	629.92	574.10	517.82	403.15	361.29
7	539.93	492.08	443.85	345.56	313.96
8	472.44	430.58	388.37	302.36	270.97
9	419.95	382.74	345.22	273.95	240.86
10	377.95	344.46	310.69	241.89	216.78
11	343.59	313.15	282.45	219.56	199.80
12	314.12	287.05	258.91	201.58	180.65
13	290.73	264.97	238.99	186.07	166.75
14	269.97	246.04	221.92	172.78	154.84
15	251.97	229.64	207.13	161.26	144.51
16	236.22	215.28	194.18	151.18	135.49
17	222.33	202.62	182.76	142.28	125.06
18	209.97	191.18	172.61	134.38	120.43
19	198.92	181.12	163.52	127.72	114.09
20	188.98	172.23	155.35	120 95	108.39
21	179.98	164.02	147.95	115.19	103.23
22	170.28	156.57	141.23	109.95	98.53
23	164.33	149.76	135.08	105.17	94.25
24	157.48	143.53	129.46	100.79	90.32
25	151.18	137.78	124.28	96.76	86.71
26	145.37	132.79	119.50	93.03	83.37
27	139.98	127.58	115.07	89.58	80.28
28	134.98	123.02	110.96	86.39	77.42
29	130.33	118.79	107.14	83.41	74.75
30	125.98	114.82	103.56	80.63	72.25
32	118.11	107.65	97.09	75.55	67.74
34	111.16	101.31	91.38	71.14	63.75
36	104.99	95.68	86.30	67.19	60.21
38	99.46	90.65	81.76	63.65	57.04
40	94.49	86.11	77.67	60.47	54.19
42	89.99	82.00	73.97	57.59	51.61

TABLE—(*Continued*)

OF SAFE WORKING EXTERNAL PRESSURES ON FLUES 10 FEET LONG.

BIRMINGHAM GAUGE.	3	4	5	6	7	8
Thickness of Iron.	.259	.238	.220	.203	.180	.165
Diam. in In.						
6	300.49	253.73	216.81	184.59	145.14	121.95
7	257.56	217.49	185.83	158.22	124.40	104.53
8	225.36	190.30	162.60	138.45	108.85	91.46
9	200.32	169.16	140.83	123.06	96.76	81.30
10	180.29	152.24	130.08	110.76	87.08	73.17
11	163.90	138.40	118.26	100.69	79.16	66.51
12	150.24	126.87	108.40	92.30	72.56	60.97
13	138.69	117.11	100.06	85.20	66.98	56.28
14	128.78	108.74	92.92	79.11	62.20	52.26
15	120.19	101.49	86.72	73.83	58.05	48.78
16	112.68	95.15	81.30	69.22	54.42	46.10
17	106.05	89.55	76.51	65.15	51.22	43.04
18	100.16	84.58	72.26	61.53	48.37	40.65
19	94.89	80.13	68.46	58.29	45.83	38.51
20	90.15	76.12	65.04	55 37	43.54	36 58
21	85.85	72.49	61.92	52.74	41.46	34.84
22	81.95	69.20	59.12	50.34	39.58	33.25
23	78.38	66.19	56.55	48.15	37.86	31.81
24	75.12	62.43	54 20	46.14	36.28	30.48
25	72.11	60.89	52.11	44.30	34.83	29.26
26	69.34	58.55	50.03	42.59	33.49	28.91
27	66.77	56.38	48.17	41.02	32.25	27.10
28	64.38	54.37	46.45	39.55	31.10	26.13
29	62.16	52.49	44.85	38.19	30.02	25.23
30	60.09	50.74	43.36	36.91	29.02	24.39
32	56.34	47.57	40.65	34.61	27.21	22.86
34	53.02	44.77	38.25	32.57	25.61	21.52
36	50.08	42.38	36.13	30.76	24.18	20.32
38	47.44	40.06	34.23	29.14	22.91	19.25
40	45.07	38.06	32.52	27.68	21.77	18.29
42	42.13	36.24	30.97	26.37	20.73	17.42

TABLE—(*Continued*)

OF SAFE WORKING EXTERNAL PRESSURES ON FLUES 20 FEET LONG.

BIRMINGHAM GAUGE.	$\frac{3}{8}$	00	0	1	2
Thickness of Iron.	.375	.358	.340	.300	.284
Diam. in In.					
6	314.96	287.05	258.91	201.58	180.65
7	269.97	246.04	221.93	172.78	156.98
8	236.22	215.29	194.18	151.18	135.49
9	209.97	191.37	172.61	136.98	120.43
10	188.98	172.23	155.35	120.95	108.39
11	171.80	156.57	141.26	109.78	99.90
12	157.06	143.53	129.46	100.79	90.32
13	145.37	132.49	119.50	93.03	83.38
14	134.98	123.02	110.96	86.39	77.42
15	125.98	114.78	103.56	80.63	72.26
16	118.11	107.64	97.09	75.59	67.74
17	111.16	101.31	91.38	71.14	62.53
18	104.99	95.59	86.31	67.19	60.22
19	99.46	90.56	81.76	63.86	57.05
20	94.49	86.12	77.68	60.47	54.19
21	89.99	82.01	73.98	57.59	51.61
22	85.14	78.29	70.62	54.98	49.27
23	82.16	74.88	67.54	52.58	47.13
24	78.74	71.76	64.73	50.39	45.16
25	75.59	68.89	62.14	48.38	43.36
26	72.68	66.54	59.75	46.52	41.68
27	69.99	63.79	57.54	44.59	40.14
28	67.49	61.51	55.48	43.20	38.71
29	65.17	59.39	53.57	41.70	37.37
30	62.99	57.42	51.78	40.31	36.12
32	59.06	53.82	48.55	37.77	33.87
34	55.58	50.66	45.69	35.57	31.87
36	52.50	47.84	43.15	33.59	30.10
38	49.73	45.38	40.88	31.82	28.52
40	47.24	43.05	38.83	30.23	27.09
42	44.99	41.00	36.98	28.79	25.80

TABLE—(*Concluded*)

OF SAFE WORKING EXTERNAL PRESSURES ON FLUES 20 FEET LONG.

BIRMINGHAM GAUGE.	3	4	5	6	7	8
Thickness of Iron.	.259	.238	.220	.203	.180	.165
Diam. in In.						
6	150.25	126.87	108.40	92.30	72.57	60.98
7	128.78	108.75	92.92	79.11	62.20	52.27
8	112.68	95.15	81.30	69.22	54.43	45.73
9	100.16	84.58	70.42	61.53	48.38	40.65
10	90.15	76.12	65.04	55.38	43.54	36.58
11	81.95	69.20	59.13	50.35	39.58	33.25
12	75.12	63.44	54.20	46.15	36.28	30.48
13	69.35	58.56	50.03	42.60	33.49	28.14
14	64.39	54.37	46.46	39.55	31.10	26.13
15	60.10	50.75	43.36	36.91	29.02	24.39
16	56.34	47.58	40.65	34.61	27.21	23.05
17	53.03	44.78	38.25	32.57	25.61	21.52
18	50.08	42.29	36.13	30.76	24.18	20.32
19	47.45	40.07	34.23	29.14	22.91	19.25
20	45.08	38.06	32.52	27.68	21.71	18.29
21	42.93	36.24	30.96	26.37	20.73	17.42
22	40.98	34.60	29.56	25.17	19.79	16.62
23	39.19	33.09	28.27	24.07	18.93	15.90
24	37.56	31.71	27.10	23.07	18.14	15.24
25	36.05	30.44	26.05	22.15	17.41	14.63
26	34.67	29.27	25.01	21.29	16.74	14.45
27	33.38	28.19	24.08	20.51	16.12	13.55
28	32.19	27.18	23.22	19.77	15.55	13.06
29	31.08	26.24	22.42	19.09	15.01	12.61
30	30.04	25.37	21.68	18.45	14.51	12.19
32	28.17	23.78	20.32	17.30	13.60	11.43
34	26.51	22.38	19.12	16.28	12.80	10.76
36	25.04	21.19	18.06	15.38	12.09	10.16
38	23.72	20.03	17.11	14.57	11.45	9.62
40	22.53	19.03	16.26	13.84	10.88	9.14
42	21.06	18.12	15.48	13.18	10.36	8.71

Rule *for finding the Collapsing Pressure of Boiler-Flues.*— Multiply the square of the thickness of the iron, in thirty-seconds of an inch, by the constant number 262.4; divide this product by the length of the flue in feet; divide this quotient by the diameter of the flue, in quarter feet, and the quotient will be the collapsing pressure in pounds per square inch.

EXAMPLE.

Diameter of flue, 24 inches.
Length of " 10 feet.
Thickness of iron, $\frac{3}{8}$ in.

Thickness, $\frac{3}{8} = \frac{12}{32}$.

Diam. 24 in. = 8 quarter ft.

12
12
144
262.4
576
288
864
288
10)37785.6
8)3778.56
472.32 pounds.

Explanation of the following Tables of Collapsing Pressures.— The outside vertical column on the left-hand side of the table gives the length of the flue in feet; the horizontal column at the top of the table gives the diameter of the flue in inches. All the other columns denote the collapsing pressures in pounds per square inch.

COLLAPSING PRESSURE OF WROUGHT-IRON BOILER-FLUES ¼ INCH THICK.

Length in Feet.	Diameter of Flue in Inches.									
	9	12	15	18	21	24	27	30	33	36
4	1398	1049	840	699	600	525	466	420	382	349
6	932	698	560	466	400	349	311	285	254	233
8	699	524	420	350	300	262	233	210	191	175
10	559	419	336	280	240	210	186	168	152	140
12	466	349	285	233	200	175	155	142	127	116
14	400	300	239	200	171	150	133	120	109	100
16	350	262	210	175	150	131	117	105	95	87
18	311	233	187	156	133	116	103	95	85	78
20	278	210	168	140	120	105	93	84	76	70
22	255	190	153	128	109	95	85	76	69	64
24	233	174	142	116	100	87	78	71	63	58
26	215	160	129	107	82	80	72	64	58	54
28	200	150	120	100	85	75	67	60	54	50
30	186	140	112	93	80	70	62	56	51	46
32	175	131	105	87	75	65	58	52	47	44
34	164	123	99	82	70	61	55	49	45	41
36	155	116	94	77	66	58	51	47	42	39

COLLAPSING PRESSURE OF WROUGHT-IRON BOILER-FLUES $\frac{5}{16}$ INCH THICK.

Length in Feet.	Diameter of Flue in Inches.									
	9	12	15	18	21	24	27	30	33	36
4	2187	1640	1312	1093	937	820	729	656	596	546
6	1458	1093	875	729	624	546	486	437	398	364
8	1093	820	656	546	468	410	364	328	298	273
10	875	656	525	437	374	328	292	262	238	218
12	729	546	437	364	312	273	243	218	199	182
14	625	468	375	312	267	224	208	182	170	156
16	546	410	328	273	234	205	182	164	149	136
18	486	364	292	243	208	182	162	146	133	121
20	437	328	262	218	187	164	146	131	119	109
22	398	298	238	199	170	149	133	119	108	99
24	364	273	218	182	156	136	121	109	99	91
26	336	252	202	168	144	126	112	101	92	84
28	312	234	187	156	133	117	104	93	85	78
30	291	218	175	145	125	109	97	87	79	72
32	273	205	164	136	117	102	91	82	74	68
34	257	193	154	128	110	96	86	77	70	64
36	243	182	146	121	104	91	81	73	66	60

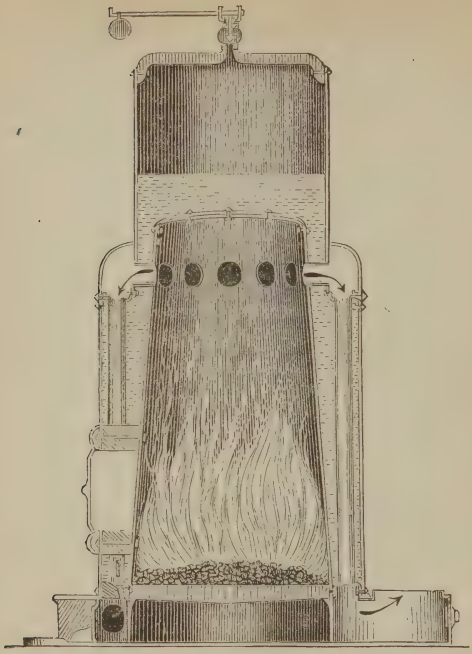
COLLAPSING PRESSURE OF WROUGHT-IRON BOILER-FLUES ⅜ INCH THICK.

Length in Feet.	Diameter of Flue in Inches.									
	9	12	15	18	21	24	27	30	33	36
4	3148	2361	1889	1574	1349	1180	1049	944	858	787
6	2099	1574	1260	1049	900	787	699	630	572	525
8	1574	1180	944	787	674	590	525	472	429	393
10	1260	945	756	630	540	472	420	378	344	315
12	1050	787	630	520	450	393	350	315	286	260
14	900	674	540	450	385	337	300	270	245	225
16	787	590	472	393	337	295	262	236	214	196
18	699	525	420	350	300	262	233	210	191	175
20	630	472	378	315	270	236	215	189	172	157
22	573	429	343	286	245	214	191	171	156	143
24	525	393	315	262	225	196	175	157	143	131
26	484	363	292	242	207	181	161	146	132	121
28	450	337	270	225	192	168	150	135	122	112
30	420	315	252	210	180	157	140	126	115	105
32	393	295	236	196	168	147	131	118	107	98
34	370	278	222	185	158	139	123	111	101	92
36	350	262	210	175	150	131	117	105	95	87

COLLAPSING PRESSURE OF WROUGHT-IRON BOILER-FLUES $\frac{7}{16}$ INCH THICK.

Length in Feet.	Diameter of Flue in Inches.									
	9	12	15	18	21	24	27	30	33	36
4	4786	3214	2571	2143	1837	1607	1428	1285	1169	1071
6	2857	2143	1714	1428	1224	1071	952	857	780	714
8	2143	1607	1285	1021	918	803	714	642	584	510
10	1714	1286	1028	857	735	643	571	514	468	428
12	1428	1071	857	714	612	535	476	428	390	357
14	1224	918	735	612	525	459	408	367	333	306
16	1071	803	642	536	459	401	357	321	292	268
18	952	714	571	476	408	357	317	285	260	238
20	857	643	514	428	367	321	289	257	234	214
22	779	584	468	390	334	292	260	234	212	195
24	714	536	428	357	306	268	238	214	195	178
26	659	494	396	330	282	247	220	198	180	165
28	612	459	367	306	262	230	204	183	167	153
30	571	428	342	285	245	214	190	171	156	142
32	536	401	321	268	229	201	179	160	146	134
34	504	378	302	252	216	189	168	151	137	126
36	476	357	285	238	204	178	159	142	130	119

THE Steam-gauge, like the Safety-valve, is a means of indicating the approach of danger; though a silent, it is no less an impressive, monitor. It does not speak, but by moving its steady hand on the face of the dial, it "points" to the danger. With a good safety-valve, good gauge-cocks, correct steam-gauge, competent inspection and careful attendance, there need be little fear of steam-boiler explosions.



THE SHAPLEY BOILER.

This boiler is vertical, in two cylindrical sections, both being connected by a horizontal tube-sheet, Z. The fire-box is conical in form and is joined to the lower section by a tube-sheet, which is convex and stayed. Below the crown-sheet of the fire-box,

and above the lower edge of the upper section, a series of 13 3-inch horizontal fire-tubes are arranged radically and secured to both. In the annular space between the fire-box and the lower section, which connects the two tube sheets, is secured a series of 26 2-inch vertical fire-tubes. The annular space above the outlets of all these tubes is confined by a movable cover — made in two parts, to facilitate the cleaning of the tubes; and below the vertical tubes communicate with an annular space around the ash-pit in the base of the boiler, from which the products of combustion escape by a pipe to the chimney. The water-level is maintained over the crown of the fire-box, covering all the tubes and wetting all the fire-surface. The upper section has a cast head provided, with the usual nozzles and valves, and a fire-door frame penetrates the lower section to the fire-box, which latter is fitted with a circular grate in the usual way. These boilers are used entirely for portable engines.

BOILER TUBES.

The object of the tube, like the flue, is to transmit the heat to the surrounding water, and conduct the smoke and gases to the chimney; but, unlike the flue, the tube may be filled with water and act as a passage for the circulation of liquids, while the flame and heat may come in contact with the outer, instead of the inner surfaces. In regard to their diameter,

mechanical construction, mode of attachment, etc., they may materially differ from flues. The resistance of tubes is due to their hardness; the materials ranging in the following order — steel, iron, brass, copper.

Iron, of late years, especially where anthracite coal has been used as fuel, has nearly superseded all other materials for tubing on account of its hardness, good flanging qualities, and the fact that it can be made lighter and still possess sufficient strength, while its steaming qualities are nearly equal to copper or brass. The failure of iron tubes may, in the majority of cases, be attributed to a contracted water-space, bad circulation, and the deposit of scale adhering to the outer surface caused by impurities in the water.

Diameter and Arrangement of Tubes.— As regards the diameter of boiler tubes, tubes of 2 inches diameter, placed in vertical rows from ¾ to 1 inch apart, have been shown to be productive of the most satisfactory results, as such an arrangement admits of an easy circulation of the water, and of the free escape of steam from the heating-surface to the steam-dome, besides giving ready access to the mud in its passage from the water to the bottom of the boiler; and also because there is much more heating-surface in a tube of this diameter of a given length, in proportion to the space it occupies, than in a larger one. Thus a tube 2 inches in diameter and 11 feet long has 829 square inches of surface, and one 4 inches in diameter has 1658 square inches, or just double the

quantity. But the four-inch tube occupies four times as much space as the other, as it is twice as high and twice as wide. Therefore, in proportion to the space it occupies, the tube which is two inches in diameter has twice the surface of the larger one. If we compare a two-inch with an eight-inch tube, we will find that the former has four times as much surface, in proportion to its size, as the eight-inch tube.

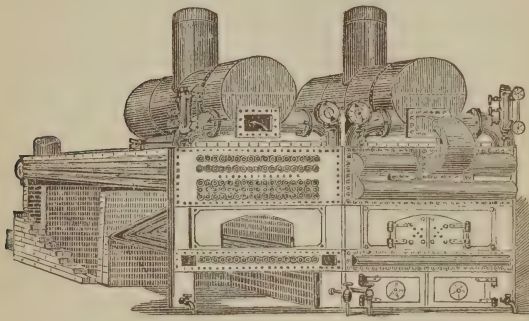
Small tubes have the additional advantages that they may be made of thinner material, and yet have the same strength to resist a bursting pressure from within, or a collapsing pressure from without, as larger tubes made of thicker metal; and that the heat inside of a thin tube is conducted to the water more rapidly than it could be through a thick one. Tubes of less diameter than two inches are not economical, as they are liable to become stopped or choked with ashes, cinders, and pieces of unburned fuel. Tubes are often crowded to an injurious extent for the purpose of getting more surface, totally disregarding the other conditions of steam-raising. Heating-surface in the abstract is one thing, its efficiency is another, as the under portions of the tubes and internal flues are almost worthless for steam-raising, not only on account of the difficulty which the steam has in escaping from the surface on one side, but also in consequence of the deposit of soot, ashes, and flue dirt, which is the rule, on the other.

In horizontal tubes various means have been re-

sorted to for the purpose of extracting more of the heat from the gases than they will yield by radiation or conduction through their mass, by breaking the current at intervals, and so bringing fresh portions of the gases in contact with the plates, and by giving them a zigzag motion; this, however, has the effect of impairing the draught, and, in most cases, of causing a reduction in the evaporative capacity of the boiler. In passing up through vertical tubes, gases act at a disadvantage for imparting their heat to the plates. The particles cooled by contact with the sides on entering, have no tendency to make way for those in the middle of the current that still retain their heat, which can therefore only be indifferently imparted by radiation or conduction.

The evaporative efficiency of tubes, as before stated, depends on the nature, condition, and thickness of the material forming the tubes, and is proportional to the distance the heat has to traverse or to the thickness of the tube, and inversely to the difference of temperature between the two surfaces. Assuming the gases entering a tube to be all of the same temperature, the particles striking against the upper surface must give up part of their heat, and, in cooling, descend by virtue of their increased gravity, despite the onward and upward force due to the momentum of the mass which opposes their descent. The hot particles immediately behind and beneath these will come in contact with the upper

surface a little farther on, and so a species of convection is kept up as the gases sweep along.



THE PHLEGER BOILER.

This consists of a number of wrought-iron tubes nearly horizontal, connected to wrought-iron tube plates and set in brickwork. There are 17 bent tubes, 2 inches in diameter and 15 feet long, so arranged as to form the furnace and water-grate, being secured at the ends to wrought-iron tube-sheets. There are also 68 straight tubes of the same dimensions, secured at the ends to wrought-iron tube-sheets. These tubes are all connected with each other and the steam-drum, which is 2½ feet diameter and 12 feet long, and which contains shelves for the prevention of foaming.

TABLE

OF SUPERFICIAL AREAS OF EXTERNAL SURFACES OF TUBES OF VARIOUS LENGTHS AND DIAMETERS IN SQUARE FEET.

The following tables are designed to facilitate the calculation of the heating-surface of the tubes in tubular boilers, and are adapted for tubes of various lengths, from 8 to 16 feet, advancing by inches, and of various diameters, from $1\frac{5}{8}$ to $2\frac{1}{4}$ inches, advancing by $\frac{1}{8}$ of an inch.

Explanation.— The large figures at the end of the horizontal lines give the length of tubes in feet, and the small intermediate figures on the same line give the additional inches. The vertical column on the left gives the diameters of the tubes in inches. The numbers in the tables represent the superficial area of our tube in square feet, and decimal parts thereof, for the different lengths and diameters of tubes required.

Example.— Required, the heating surface of 163 tubes, $1\frac{3}{4}$ inches diameter and 11 feet 10 inches long. Thus, having found the length (11 feet 10 inches) in the above-named horizontal line of figures, trace downwards to the line opposite the diameter ($1\frac{3}{4}$) in the vertical column on the left, where will be found the number 5.421, being the area of the tube, and which being multiplied by the number of tubes (163), gives the total area of 883,623 square feet, thus reducing the whole process to a simple matter of multiplication.

SUPERFICIAL AREAS OF EXTERNAL SURFACES OF TUBES OF VARIOUS LENGTHS AND DIAMETERS IN SQUARE FEET.

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	8	1	2	3	4	5	6	7	8	9	10	11
$1\frac{5}{8}$	3.403	3.438	3.474	3.509	3.545	3.580	3.616	3.651	3.686	3.722	3.757	3.793
$1\frac{3}{4}$	3.665	3.703	3.741	3.779	3.817	3.856	3.894	3.932	3.970	4.008	4.046	4.085
$1\frac{7}{8}$	3.926	3.967	4.008	4.049	4.090	4.131	4.172	4.213	4.254	4.295	4.335	4.376
2	4.188	4.232	4.276	4.319	4.363	4.406	4.450	4.494	4.537	4.581	4.624	4.668
$2\frac{1}{8}$	4.450	4.496	4.543	4.589	4.636	4.682	4.728	4.775	4.821	4.867	4.914	4.960
$2\frac{1}{4}$	4.712	4.761	4.810	4.859	4.908	4.957	5.006	5.055	5.105	5.154	5.003	5.252

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	9	1	2	3	4	5	6	7	8	9	10	11
$1\frac{5}{8}$	3.828	3.864	3.899	3.935	3.970	4.006	4.041	4.076	4.112	4.147	4.183	4.218
$1\frac{3}{4}$	4.123	4.161	4.199	4.237	4.276	4.314	4.352	4.390	4.428	4.467	4.505	4.543
$1\frac{7}{8}$	4.417	4.458	4.499	4.540	4.581	4.622	4.663	4.704	4.745	4.785	4.826	4.867
2	4.712	4.756	4.799	4.843	4.886	4.930	4.974	5.017	5.061	5.104	5.148	5.192
$2\frac{1}{8}$	5.006	5.053	5.099	5.145	5.192	5.238	5.285	5.331	5.377	5.424	5.470	5.516
$2\frac{1}{4}$	5.301	5.350	5.399	5.448	5.497	5.546	5.595	5.645	5.694	5.743	5.792	5.841

SUPERFICIAL AREAS OF EXTERNAL SURFACES OF TUBES OF VARIOUS LENGTHS AND DIAMETERS IN SQUARE FEET.

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	10	1	2	3	4	5	6	7	8	9	10	11
1⅝	4.254	4.289	4.325	4.360	4.396	4.431	4.466	4.502	4.537	4.573	4.608	4.644
1¾	4.581	4.619	4.657	4.696	4.734	4.772	4.810	4.848	4.886	4.924	4.963	5.001
1⅞	4.908	4.949	4.990	5.031	5.072	5.113	5.154	5.195	5.235	5.276	5.317	5.358
2	5.236	5.279	5.323	5.366	5.410	5.454	5.497	5.541	5.584	5.628	5.672	5.715
2⅛	5.563	5.609	5.655	5.702	5.748	5.795	5.841	5.887	5.934	5.980	6.026	6.073
2¼	5.890	5.939	5.988	6.037	6.086	6.135	6.184	6.234	6.283	6.332	6.381	6.430

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	11	1	2	3	4	5	6	7	8	9	10	11
1⅝	4.679	4.715	4.750	4.785	4.821	4.856	4.892	4.927	4.963	4.998	5.034	5.069
1¾	5.039	5.077	5.115	5.154	5.192	5.230	5.268	5.306	5.345	5.383	5.421	5.459
1⅞	5.399	5.440	5.481	5.522	5.563	5.604	5.644	5.685	5.726	5.767	5.808	5.849
2	5.759	5.803	5.846	5.890	5.934	5.977	6.021	6.064	6.108	6.152	6.195	6.239
2⅛	6.119	6.165	6.212	6.258	6.304	6.351	6.397	6.444	6.490	6.536	6.583	6.629
2¼	6.479	6.528	6.577	6.626	6.675	6.724	6.774	6.823	6.872	6.921	6.970	7.019

SUPERFICIAL AREAS OF EXTERNAL SURFACES OF TUBES OF VARIOUS LENGTHS AND DIAMETERS IN SQUARE FEET.

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	12	1	2	3	4	5	6	7	8	9	10	11
1⅝	5.105	5.140	5.175	5.211	5.246	5.282	5.317	5.353	5.388	5.424	5.459	5.494
1¾	5.497	5.535	5.574	5.612	5.650	5.688	5.726	5.764	5.803	5.841	5.879	5.917
1⅞	5.890	5.931	5.972	6.013	6.054	6.094	6.135	6.176	6.217	6.258	6.299	6.340
2	6.283	6.326	6.370	6.414	6.457	6.501	6.544	6.588	6.632	6.675	6.719	6.762
2⅛	6.675	6.722	6.768	6.814	6.861	6.907	6.954	7.000	7.046	7.093	7.139	7.185
2¼	7.068	7.117	7.166	7.215	7.264	7.314	7.363	7.412	7.461	7.510	7.559	7.608

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	13	1	2	3	4	5	6	7	8	9	10	11
1⅝	5.530	5.565	5.601	5.636	5.672	5.707	5.743	5.778	5.814	5.849	5.884	5.920
1¾	5.955	5.994	6.032	6.070	6.108	6.146	6.184	6.223	6.261	6.299	6.337	6.375
1⅞	6.381	6.422	6.463	6.504	6.544	6.585	6.626	6.667	6.708	6.749	6.790	6.831
2	6.806	6.850	6.894	6.937	6.981	7.024	7.068	7.112	7.155	7.199	7.242	7.286
2⅛	7.232	7.278	7.324	7.371	7.417	7.463	7.510	7.556	7.603	7.649	7.695	7.742
2¼	7.657	7.706	7.755	7.804	7.853	7.903	7.952	8.001	8.050	8.099	8.148	8.197

SUPERFICIAL AREAS OF EXTERNAL SURFACES OF TUBES OF VARIOUS LENGTHS AND DIAMETERS IN SQUARE FEET.

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	14	1	2	3	4	5	6	7	8	9	10	11
1⅝	5.955	5.991	6.026	6.062	6.097	6.133	6.168	6.204	6.239	6.274	6.310	6.345
1¾	6.414	6.452	6.490	6.528	6.566	6.604	6.643	6.681	6.719	6.757	6.795	6.833
1⅞	6.872	6.913	6.953	6.994	7.035	7.076	7.117	7.158	7.199	7.240	7.281	7.322
2	7.330	7.374	7.417	7.461	7.504	7.548	7.592	7.635	7.679	7.722	7.766	7.810
2⅛	7.788	7.834	7.881	7.927	7.973	8.020	8.066	8.113	8.159	8.205	8.252	8.298
2¼	8.246	8.295	8.344	8.393	8.443	8.492	8.541	8.590	8.639	8.688	8.737	8.786

DIAM. OF TUBE.	FEET.	INCHES.										
Inches.	15	1	2	3	4	5	6	7	8	9	10	11
1⅝	6.381	6.416	6.452	6.437	6.523	6.558	6.594	6.629	6.664	6.700	6.735	6.771
1¾	6.872	6.910	6.948	6.986	7.024	7.063	7.101	7.139	7.177	7.215	7.253	7.292
1⅞	7.363	7.403	7.444	7.485	7.526	7.567	7.608	7.649	7.690	7.731	7.772	7.812
2	7.854	7.897	7.941	7.984	8.028	8.072	8.115	8.159	8.202	8.246	8.290	8.333
2⅛	8.344	8.391	8.437	8.483	8.530	8.576	8.622	8.669	8.715	8.762	8.808	8.854
2¼	8.835	8.884	8.933	8.982	9.032	9.081	9.130	9.179	9.228	9.277	9.326	9.375

TABLE

OF SUPERFICIAL AREAS OF TUBES OF DIFFERENT LENGTHS AND DIAMETERS FROM 2½ INCHES TO 3 INCHES AND FROM 8 FEET TO 20 FEET.

Diam. inches.	Length in feet.	Super. area in inches.	Super. area in feet.	Diam. inches.	Length in feet.	Super. area in inches.	Super. area in feet.
2½	8	753.984	5.23	2¾	15	1555.092	10.79
"	9	848.232	5.89	"	16	1658.764	11.51
"	10	942.480	6.54	"	17	1762.437	12.23
"	11	1036.728	7.19	"	18	1738.110	13.07
"	12	1130.976	7.85	"	19	1969.783	13.67
"	13	1225.224	8.50	"	20	2073.456	14.39
"	14	1319.472	9.16	3	8	904.780	6.28
"	15	1413.720	9.81	"	9	1017.878	7.06
"	16	1507.968	10.47	"	10	1130.976	7.85
"	17	1602.216	11.12	"	11	1244.073	8.63
"	18	1696.464	11.78	"	12	1357.171	9.42
"	19	1790.712	12.43	"	13	1470.268	10.21
"	20	1884.960	13.09	"	14	1583.366	10.99
2¾	8	829.382	5.75	"	15	1696.464	11.78
"	9	869.055	6.03	"	16	1809.561	12.56
"	10	1036.728	7.19	"	17	1922.659	13.35
"	11	1140.400	7.91	"	18	2035.756	14.13
"	12	1244.073	8.63	"	19	2148.854	14.92
"	13	1347.746	9.35	"	20	2261.952	15.70
"	14	1451.419	10.07	"			

STEAM-BOILER CONNECTIONS AND ATTACHMENTS.

The same apparent want of skill that is so frequently shown in the setting and location of steam-boilers may be observed in the arrangement of their connections and attachments. Those whose duty it was to connect a boiler with the object for which it

was intended, frequently proceeded without any calculation whatever as to how the work would come together or finish; consequently it is nothing uncommon to see some very uncouth arrangements. Pipes are often used either too large or too small for the purpose for which they are intended. Again, they are cut without any degree of accuracy, and have to be bent and strained to bring them together. The consequence is that they are subjected to an enormous strain induced by contraction and expansion, causing leakage, besides incurring the dangers that may result from a pipe or connection breaking while under pressure.

An instance of such blundering occurred in this city. A steam-pipe, four inches in diameter, was attached to a boiler in such a manner that it could not be connected at the other end, and, instead of bending it, the steam-fitter sprung it, requiring four men with a long lever to do so. Then, as soon as it was connected and the steam turned on, the strain induced by the expansion of the pipe forced one of the cast-iron connections to break. The consequence was the engineer was killed and five or six others badly scalded. Every intelligent engineer is well aware that the straighter and more direct a pipe is, for whatever purpose employed, the more satisfactory will be the result; and yet how common it is to see pipes, for the purpose of conveying water or steam, bent in almost every imaginable direction, and as

many as a dozen elbows and couplings used for the purpose of connecting them, when by the exercise of ordinary skill and good judgment two or three would answer.

Such botching is a reproach on the men calling themselves mechanics that do it, and could find no reasonable excuse save in the fact that the same want of skill, carelessness, and recklessness is to be found in almost everything else connected with steam-boiler engineering. A steam-fitter guaranteed the owner of a steam-boiler that he would furnish dry steam to his engine if he would allow him to alter the steam-pipe, which at the time was very straight and direct. He altered the pipe to the shape of two double cranks, and instead of three elbows, which were used before the alteration was made, it became necessary to use eleven. As a result the steam-cylinder was continually flooded with the water of condensation, and the power of the engine so diminished that the arrangement had to be taken down and replaced with the straight pipe, which involved a great loss both in time and expense.

GAUGE-COCKS.

The gauge-cock is one of the most indispensable adjuncts of the steam-boiler. It is as important as the safety-valve, as, without some reliable means for determining the height or the level of the water in

steam-boilers, there would be no guarantee of safety, even under the most intelligent and careful management. But the advantage of the gauge-cock has not always been appreciated, proof of which may be found in the wretched condition in which they are frequently found on boilers. It is not uncommon to find them leaking, covered with mud, filled solid with deposit from the water, or broken off even with the head of the boiler and plugged up. It might be reasoned that their importance to engineers, firemen, and owners of steam-boilers would entitle them to more careful and better treatment; but as every other attachment of the steam-boiler, as well as the boiler itself, has been in the past subject to neglect, abuse, and harsh treatment, it would be a wonder if the gauge-cock escaped. Gauge-cocks require frequent examining and blowing out, but when opened it should not be done with a snap, but gradually; nor should they be closed with a jerk or a thump. They should also be frequently ground on their seats for the purpose of making them steam- and water-tight, as whenever they are found leaking, or looking as if they were not cared for, it furnishes indisputable evidence that there is ignorance and mismanagement somewhere.

KEEP everything about the Boiler-room neat and clean. When water- and steam-gauges are dirty and corroded, and the boiler-heads and furnace-doors covered with dirt, it is a sure sign that there is poor management throughout the establishment.

STEAM-GAUGES.

The object of the steam-gauge is to indicate the steam pressure in the boiler, in order that it may not be increased far above that at which the boiler was originally considered safe; and it is as a provision against this contingency that a really good gauge is a necessity where steam is employed, for no guide at all is vastly better than a false one. The most essential requisites of a good steam-gauge are, that it be accurately graduated, and that the material and workmanship be such that no sensible deterioration may take place in the course of its ordinary use.

The pecuniary loss arising from any considerable fluctuation of the pressure of steam has never been properly considered by the proprietors of engines. If steam be carried too high, the surplus will escape through the safety-valve, and all the fuel consumed to produce such excess is so much dead loss. On the other hand, if there be at any time too little steam, the engine will run too slow, and every lathe, loom, or other machine driven by it, will lose its speed and of course its effective power in the same proportion.

A loss of one revolution in ten at once reduces the productive power of every machine driven by the engine ten per cent., and loses to the proprietor ten

per cent. of the time of every workman employed to manage such machine. In short, the loss of one revolution in ten diminishes the productive capacity of the whole concern ten per cent., so long as such reduced rate continues; while the expenses of conducting the shop (rent, wages, insurance, etc.,) all run on as if everything was in full motion. A variation to this amount is a matter of frequent occurrence, and is, indeed, unavoidable, unless the engineer is afforded facilities to prevent it.

A very little reflection will satisfy any one that it must be a very small concern, indeed, in which a half-hour's continuance of it would not produce a result more than enough to defray the cost of a very expensive instrument to prevent it. If the engineer, to avoid this loss, keeps a surplus of steam constantly on hand, he is constantly wasting the steam, and consequently fuel, thus incurring another loss, which, though less alarming than the first, will yet be serious, and render any instrument most desirable which can prevent it.

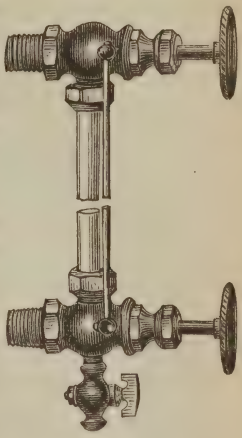
It is, therefore, of great importance to the proprietors of engines to have an instrument which can constantly indicate the pressure in the steam-boilers with accuracy. This would enable the engineer to keep his steam at a constant pressure, thus avoiding waste of fuel on the one hand, and the still more serious loss of the productive power of the shop on the other. An instrument, therefore, constantly

indicating the pressure of steam, reliable in its character, and, with ordinary care, not subject to derangement, is evidently a desideratum both to the engineer and proprietor. The importance of such an instrument, as a preventive of explosion, and of the frightful consequences to life and limb, and ruinous pecuniary results of such disaster, is obvious on the slightest consideration; but the value of the instrument, in the economical results of its daily use, is by no means properly appreciated.

Steam-gauges are made in various forms, but they may be divided into two general classes — spring and mercury. The spring-gauge, in consequence of being cheaper, more compact and durable than the mercury-gauge, is more generally used on stationary and locomotive boilers; but it is less reliable than the latter — reliability being the great desideratum in a steam-gauge. Every steam-gauge should be tested at least once a year by parties having proper facilities for doing that kind of work. They should be tested by the direct application of a column of mercury, and no reliance whatever should be placed upon so-called standard spring-gauges, as they are themselves frequently out of order. The market is flooded with inferior steam-gauges, as with all other attachments and adjuncts for the steam-boiler, and no manufacturer, steam-user, or engineer should attach a steam-gauge to any boiler unless he knows that it was made by manufacturers of good repute.

GLASS WATER-GAUGES.

The glass water-gauge may be said to be one of the simplest, as well as one of the most useful attachments of the steam-boiler, as by it the engineer can see, at a glance, the level of the water. No other method of determining the height of water in steam-boilers can be so convenient as a well-made glass water-gauge. They have, therefore, been almost universally used since their introduction to the present time. It consists of a thick, well-annealed glass tube, connected with two valves, the lower one of which enters the water, and the upper the steam space of the boiler, by means of which the level of the water is indicated directly in the tube.



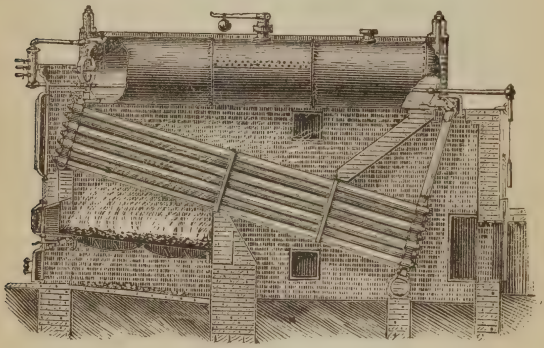
Glass water-gauges require frequent blowing out, as the tube soon becomes discolored, and the lower, or water connection, is liable to be filled with mud. This can be done by opening the drip at the bottom of the gauge, and closing the water-valve, when the steam will rush down through the tube and remove any deposit that may be on the inside of the glass.

Should it become necessary to use a swab, it must, in all cases, be of wood and covered with cloth, as the touch of any hard substance on the inside of the glass produces an immediate abrasion. If the end of the swab be dipped in acetic acid, it has the effect of removing all discoloration from the inside of the tube. The gum used for packing the steam- and water-ends of the tube should be pure, without any cloth, so that when the gas becomes heated it may expand freely; care should also be taken that the steam- and water-valves are perfectly in line, as, if their centres be out of true ever so little, the expansion of the metal will cause the glass to break. Glass water-gauges, as a means of determining the level of the water in steam-boilers, are not as reliable as the gauge-cock.

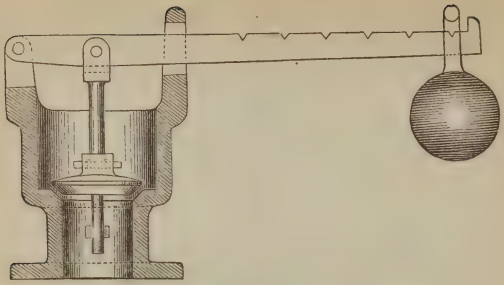
THE BABCOCK AND WILCOX'S SECTIONAL STEAM-BOILER.

The opposite cut represents the Babcock and Wilcox's Sectional Steam-boiler, one of the best known, and most extensively used of all that class of boilers now in use; and it will be observed by the engraving that the tubes of this boiler are placed in an inclined position, so that there is a strong circulation induced through the heat applied at the more elevated portion, and they are connected with the steam-drum at both ends in such a way as to give

free passage to the moving column of liquid. The choking and incrustation of the tubes is in a great measure prevented by means of the mud-drum connected with their lower ends, and every part of the apparatus can be readily reached by a cleaning-rod, and thus kept in good condition.



The most recent improvement introduced into the construction of this boiler is in the joints which connect the several tubes together. These connections are now made by means of steel castings, with expanded joints, so constructed that if a single tube should be injured in any way, it is very easily replaced; and, as these connections never come in contact with the flame or gases from the fire, they last for an indefinite period.



SAFETY-VALVES.

The form and construction of this indispensable adjunct to the steam-boiler are of the highest importance, not only for the preservation of life and property, which would, in the absence of that means of "safety," be constantly jeopardized, but also to secure the durability of the steam-boiler itself. And yet, judging from the manner in which many things called safety-valves have been constructed of late years, it would appear that the true principle by which *safety* is sought to be secured by this most valuable adjunct is either not well understood, or is disregarded by many engineers and boiler-makers.

Boiler explosions have, in many cases, occurred when, to all appearance, the safety-valves attached have been in good working order; and coroners' juries have not unfrequently been puzzled, and sometimes guided to erroneous verdicts, by scientific

evidence adduced before them, tending to show that nothing was wrong with the safety-valves, and that the devastating catastrophes could not have resulted from over-pressure, because in such case the safety-valve would have prevented them.

It is supposed that a gradually increasing pressure can never take place if the safety-valve is rightly proportioned, and in good working order. Upon this assumption, universally acquiesced in, when there is no accountable cause, explosions are attributed to the "sticking" of the valves, or to "bent" valve-stems, or inoperative valve-springs. As the safety-valve is the sole reliance, in case of neglect or inattention on the part of the engineer or fireman, it is important to examine its mode of working closely.

Safety-valves are usually provided with a spindle or guide-pin, attached to the under side, and passing through a cross-bar within the boiler, directly under the seating of the valve, which may be seen in the cut on page 176. Now, it is evident that if this guide-pin becomes bent from careless handling, the safety-valve may be rendered almost inoperative, and, instead of releasing the pressure at the point indicated, it will turn sideways, and allow only a small aperture for the escape of steam, and, further, it will not return perfectly to its seat; hence a leaky valve is the result, and to overcome this difficulty ignorant engineers and firemen generally resort to

extra weighting; and it is not uncommon to find double or treble the weight corresponding to the pressure required in the boiler.

Another difficulty is that safety-valve levers sometimes get bent, and the weight consequently hangs on one side of the true centre; this, it will be seen, causes the valve to rest more heavily on one side than on the other, and the greater the added weight the greater the difficulty. The seats of safety-valves should be examined frequently, to see that no corrosion has commenced; as valves, especially if leaky, become corroded, and often *stick fast*, so that no little force is required to raise them. If, when a safety-valve is properly weighted, it should be found leaking, do not put on extra weights, but immediately make an examination, and, in all probability, the seat or guide-pin will be found corroded, or there will be foreign matter between the valve and its seat. By taking the lever in the hand, and raising it from its seat a few times, any substance that may have kept it from its seat will be dislodged: or it may turn out on examination that the lever had deviated from some cause from a true centre. Such difficulties can be easily righted, but extra weight should never be added, as it only aggravates the trouble, instead of remedying it.

When the weight of the safety-valve is set on the lever at safe working pressure, or at the distance from the fulcrum necessary to maintain the

pressure required to work the engine, any extra length of lever should then be cut off, as a precaution to prevent the moving out of the weight on the lever, for the purpose of increasing the pressure, as, while the lever remains sufficiently long, the weight can be increased to a dangerous extent without attracting any attention; while if the lever is cut off at the point at which the safe working pressure is designated, any extra increase of pressure can only be accomplished by adding more weight to the lever, which is tolerably sure to attract the attention of some one interested in the preservation of the lives and properties of persons in the immediate vicinity.

The bolts that form the connection between the lever, fulcrum, and valve-stem should be made of brass, in order to prevent the possibility of corrosion, "sticking," or becoming magnetized, as it is termed; and for the same reason the valve and seat should be made of two different metals. When safety-valves become leaky they should be taken out and reground on their seats, for which purpose pulverized glass, flour of emery, or the fine grit or mud from grinding-stone troughs are the most suitable material; but whether they leak or not, they should be taken apart at least once a year and all the working parts cleaned, oiled, and readjusted.

The safety-valve is designed on the assumption that it will rise from its seat under the statical pressure in the boiler, when this pressure exceeds the ex-

terior pressure on the valve, and that it will remain off its seat sufficiently far to permit all the steam which the boiler can produce to escape around the edges of the valve. The problem then to be solved is, What amount of opening is necessary for the free escape of the steam from the boiler under a given pressure? The area of a safety-valve is generally determined from formulæ based on the velocity of the flow of steam under different pressures, or upon the results of experiments made to ascertain the area necessary for the escape of all the steam a boiler could produce under a given pressure. But as the fact is now generally recognized by engineers that valves do not rise appreciably from their seats under varying pressures, it is of importance that in practice the outlets round their edges should be greater than those based on theoretical considerations.

The next point to be considered is how high any safety-valve will rise under the influence of a given pressure. This question cannot be determined theoretically, but has been settled conclusively by Burg, of Vienna, who made careful experiments to determine the actual rise of safety-valves above their seats. His experiments show that the rise of the valve diminishes rapidly as the pressure increases.

TABLE

SHOWING THE RISE OF SAFETY-VALVES, IN PARTS OF AN INCH, AT DIFFERENT PRESSURES.

Lbs. 12	Lbs. 20	Lbs. 35	Lbs. 45	Lbs. 50	Lbs. 60	Lbs. 70	Lbs. 80	Lbs. 90
$\frac{1}{36}$	$\frac{1}{48}$	$\frac{1}{54}$	$\frac{1}{65}$	$\frac{1}{86}$	$\frac{1}{86}$	$\frac{1}{132}$	$\frac{1}{168}$	$\frac{1}{168}$

Taking ordinary safety-valves, the average rise for pressures from 10 to 40 pounds is about $\frac{1}{40}$ of an inch, from 40 to 70 pounds about $\frac{1}{80}$, and from 70 to 90 pounds about $\frac{1}{120}$ of an inch. The following table gives the result of a series of experiments made at the Novelty Iron-Works, New York, for the purpose of determining the exact area of opening necessary for safety-valves, for each square foot of heating-surface, at different boiler pressures.

TABLE.

Pressure in Boiler in pounds above the Atmosphere.	Area of Orifice in square inch for each square foot of Heating Surface.	Pressure in Boiler in pounds above the Atmosphere.	Area of Orifice in square inch for each square foot of Heating Surface.	Pressure in Boiler in pounds above the Atmosphere.	Area of Orifice in square inch for each square foot of Heating Surface.
0.25	.022794	10	.005698	70	.001015
0.5	.021164	20	.003221	80	.000892
1	.018515	30	.002244	90	.000796
2	.014814	40	.001723	100	.000719
3	.012345	50	.001398	150	.000481
4	.010582	60	.001176	200	.000364
5	.009259				

TABLE

OF COMPARISON BETWEEN EXPERIMENTAL RESULTS AND THEORETICAL FORMULÆ.

Boiler Pressure, 45 Pounds.			Boiler Pressure, 75 Pounds.		
Heating Surface.	Area of Opening found by Experiment.	Area of Opening according to Formulæ.	Heating Surface.	Area of Opening found by Experiment.	Area of Opening according to Formulæ.
Sq. Feet.	Sq. Ins.	Sq. Ins.	Sq. Feet.	Sq. Ins.	Sq. Ins.
100	.089	.09	100	.12	.12
200	.180	.19	200	.24	.24
500	.45	.48	500	.59	.59
1000	.89	.94	1000	1.20	1.18
2000	1.78	1.90	2000	2.40	2.37
5000	4.46	4.75	5000	6.00	5.95

Now, if we compare the area of openings, according to these experiments, with Zeuner's formula, which is entirely theoretical, it will be observed that the results from the two sources are almost identical, or so nearly so as not to make any very material difference. In the absence of any generally recognized rule, it is customary for engineers and boiler-makers to proportion safety-valves according to the heating-surface, grate-surface, or horse-power of the boiler. While one allows 1 inch of area of safety-valve to 66 square feet of heating-surface, another gives 1 inch area of safety-valve to every 4-horse power; while a third proportions his by the grate-surface,—it being the custom in such cases to allow 1 inch area of safety-valve to $1\frac{3}{4}$ square feet of grate-surface. This latter proportion has been proved by

long experience and a great number of accurate experiments, to be capable of admitting of a free escape of steam without allowing any material increase of the pressure beyond that for which the valve is loaded, even when the fuel is of the best quality, and the consumption as high as 24 pounds of coal per hour per square foot of grate-surface, providing, of course, that all the parts are in good working order. It is obvious, however, that no valve can act without a slight increase of pressure, as, in order to lift at all, the internal pressure must exceed the pressure due to the load.

The lift of safety-valves, like all other puppet-valves, decreases as the pressure increases; but this seeming irregularity is but what might be required of an orifice to satisfy appearances in the flow of fluids, and may be explained as follows: a cubic foot of water generated into steam at one pound pressure per square inch above the atmosphere, will have a volume of about 1600 cubic feet. Steam at this pressure will flow into the atmosphere with a velocity of 482 feet per second. Now suppose the steam was generated in five minutes, or in 300 seconds, and the area of an orifice to permit its escape as fast as it is generated be required, 1600 divided by 482 × 300 will give the area of the orifice, $1\frac{3}{5}$ square inches. If the same quantity of water be generated into steam at a pressure of 50 pounds above the atmosphere, it will possess a volume of 440 cubic feet, and will flow

into the atmosphere with a velocity of 1791 feet per second. The area of an orifice to allow this steam to escape in the same time as in the first case, may be found by dividing 440 by 1791×300, the result will be $\frac{3}{2}\frac{3}{5}$ square inches, or nearly $\frac{1}{8}$ of a square inch, the area required. It is evident from this that a much less lift of the same valve will suffice to discharge the same weight of steam under a high pressure than under a low one, because the steam under a high pressure not only possesses a reduced volume, but a greatly increased velocity; it is also obvious from these considerations that a safety-valve, to discharge steam as fast as the boiler can generate it, should be proportioned for the lowest pressure.

RULES.

Rule *for finding the Weight necessary to put on a Safety-valve Lever, when the Area of Valve, Pressure, etc., are known.*— Multiply the area of valve by the pressure in pounds per square inch; multiply this product by the distance of the valve from the fulcrum; multiply the weight of the lever by one-half its length (or its centre of gravity); then multiply the weight of valve and stem by their distance from the fulcrum; add these last two products together, subtract their sum from the first product, and divide the remainder by the length of the lever: the quotient will be the *weight* required.

EXAMPLE.

Area of valve, 12 inches.	65	13	8
Pressure, 65 pounds.	12	16	4
Fulcrum, 4 inches.	780	78	32
Length of lever, 32 inches.	4	13	
Weight of lever, 13 pounds.	3120	208	
Weight of valve and stem, 8 pounds.	240	32	
	32)2880	240	
	90 lbs.		

Rule *for finding the Pressure per Square Inch when the Area of Valve, Weight of Ball, etc., are known.*— Multiply the weight of ball by length of lever, and multiply the weight of lever by one-half its length (or its centre of gravity); then multiply the weight of valve and stem by their distance from the fulcrum. Add these three products together. This sum, divided by the product of the area of valve, and its distance from the fulcrum, will give the pressure in pounds, per square inch.

EXAMPLE.

Area of valve, 7 inches.	50	12	6
Fulcrum, 3 inches.	30	15	3
Length of lever, 30 inches.	1500	60	18
Weight of lever, 12 pounds.	180	12	
Weight of ball, 50 pounds.	18		
Weight of valve and stem, 6 pounds.		180	7
	21)1698		3
	80.85 lbs.		21

Rule *for finding the Pressure at which a Safety-valve is Weighted when the Length of Lever, Weight of Ball, etc., are known.*— Multiply the length of lever in inches by the weight of ball in pounds; then multiply the area of valve by its distance from the fulcrum; divide the former product by the latter: the quotient will be the pressure in pounds per square inch.

EXAMPLE.

Length of lever, 24 inches.	52	7
Weight of ball, 52 pounds.	24	3
Fulcrum, 3 inches.	208	21
Area of valve, 7 inches.	104	
	21)1248	
	59.42 lbs.	

The above rule, though very simple, cannot be said to be exactly correct, as it does not take into account the weight of the lever, valve, and stem.

Rule *for finding Centre of Gravity of Taper Levers for Safety-valves.*— Divide the length of lever by two (2); then divide the length of lever by six (6), and multiply the latter quotient by width of large end of lever less the width of small end, divided by width of large end of lever plus the width of small end. Subtract this product from the first quotient, and the remainder will be the distance in inches of the centre of gravity from large end of lever.

EXAMPLE.

Length of lever ..... 36 inches.
Width of lever at large end ..... 3 "
Width of lever at small end ..... 2 "

$36 \div 2 = 18 - 1.2 = 16.8$ inch. $36 \div 6 = 6 \times 1 = 6 \div 5 = 1.2$.

Centre of gravity from large end, 16.8 inches.

The safety-valve has not received that attention from engineers and inventors which its importance as a means of safety so imperatively deserves. In the construction of most other kinds of machinery, continual efforts have been made to insure accuracy; while in the case of the safety-valve, very little improvement has been made either in design or fitting. It is difficult to see why this should be so, when it is known that deviations from exactness, though trifling in themselves, when multiplied, not only affect the free action and reliability of machines, but frequently result in serious injury, more particularly in the case of safety-valves.

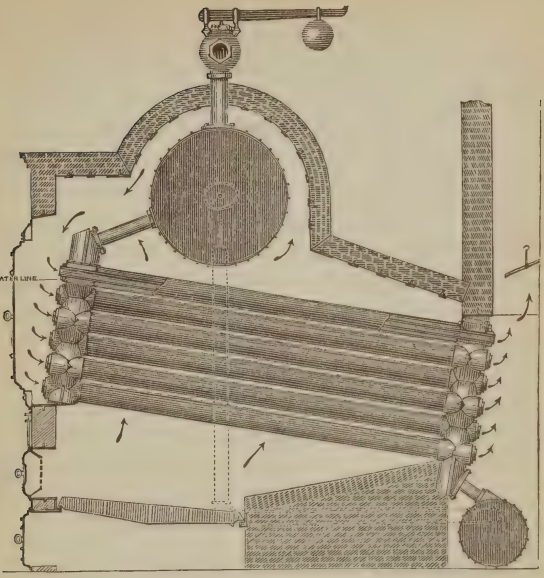
Safety-valves should never be made with rigid stems, as, in consequence of the frequent inaccuracy of the other parts, the valve is prevented from seating, thereby causing leakage; as a remedy for which, through ignorance or want of skill, more weight is added on the lever, which has a tendency to bend the stem, thus rendering the valve a source of danger instead of a means of safety. The stem should, in all cases, be fitted to the valve with a ball

and socket-joint, or a tapering stem in a straight hole, which will admit of sufficient vibration to accommodate the valve to its seat. It is also advisable that the seats of safety-valves, or the parts that bear, should be as narrow as circumstances will permit, as the narrower the seat the less liable the valve is to leak, and the easier it is to repair when it becomes leaky.

All compound or complicated safety-valves *should be avoided, as a safety-valve is, in a certain sense, like a clock — any complication of its parts has a tendency to affect its reliability and impair its accuracy.*

WITTINGHAM'S TUBULOUS BOILER.

This boiler, shown on opposite page, may be said to consist of a series of tubes, a steam- and a mud-drum. The tubes are placed angularly, and the two drums are placed horizontally and transversely to the tubes. There is also a water-drum, which is added or not, as circumstances may demand. Inside these tubes are others, of much smaller diameter, which pass entirely through the larger ones and the castings. These inner tubes are threaded at each end, and nuts on them, with faced collars, enable them to serve as both stay-bolts and flues, as, by screwing up the nuts, the outer tubes are pressed into their seats, and tight joints are secured. The mechanical construction of this boiler is of the most perfect character; it



is very durable, and keeps perfectly tight. It has a good reputation for efficiency, durability, and economy.

FOAMING IN STEAM-BOILERS.

The tendency of the water in a steam-boiler to rise into the cylinder is well known to engineers, and is generally attributed to the presence of dirt, grease, and other soapy substances. But it frequently arises

from a disturbance of the relation existing between the temperature and elasticity of the steam in the boiler, as, when the discharge of steam is out of proportion to the steam-room in the boiler, the high temperature required to generate steam with sufficient rapidity to supply the demand causes violent boiling, and the agitation is greater when the relation between the temperature and pressure is most disturbed. This is often the case with tug-boats just starting to tow a heavy vessel, or a locomotive starting a train of cars, and even with stationary boilers having too limited steam capacity, when a heavy piece of machinery is thrown on.

The most common causes of foaming are insufficient steam-room, foulness of boilers, excessive firing, and the effects produced by the intermittent action of the steam-valves. The supply of steam to the cylinder being cut off for a considerable period during each stroke, the effect is to throw the water in the boiler into a slight undulatory motion, as may frequently be observed in the glass water-gauge. Foaming in locomotive boilers is generally caused by impurities in water, which are confined to certain parts of the country known as the alkali regions; these impurities consist essentially of potash, soda, ammonia, and lithia. Locomotive boilers using surface water are also apt to foam if allowed to become dirty, in consequence of decayed vegetable matter being held in suspension in the water, such sedimen-

tary accumulations adding to the strength of the ingredients above referred to.

Foaming in marine boilers is most generally caused by changing the water from salt to fresh, or *vice versâ*, and is made evident by the boiling up of the water in the glass gauge. When foaming arises from this cause, the water in the boiler should be changed as soon as possible, which can be done by putting on a strong feed and blowing out continuously, or at short intervals; and it may become necessary to throttle down the steam, cut off short by the link, or even to stop the engine in order to ascertain the level of the water in the boilers, when it will frequently be found to have fallen below the proper level. Violent foaming can be checked by opening the furnace door and damper, and covering the fire with fresh coal; but this means of relief should be used as little as possible, because it has a tendency to injure the boiler, owing to the sudden contraction of the parts most exposed to the fire.

Foaming is also inherent in some types of boilers, in consequence of their peculiar construction, which prevents a free escape of the steam from the heating-surface to the steam-room. Boilers with a large amount of heating-surface and small steam-room generally foam; so also do boilers with the ordinary amount of steam-room, if the water be carried too high. Various expedients have been resorted to, such as perforated pipes, baffle-plates, etc., to counter-

act the dangers induced by foaming, but without any permanent results. Experience has shown that the most reliable preventives of foaming are, ample steam-room, good circulation, clean boilers, and moderate firing. All the phenomena connected with foaming have not yet been satisfactorily explained; but, from whatever cause it may arise, it is always attended with a certain amount of danger. *Foaming* is sometimes confounded with *priming*, but they arise from very different causes, and are productive of very different results. *Foaming* may result in permanent injury to a boiler, or even induce explosions, while *priming* can only cause a waste of fuel and loss of power. *Foaming* is always made manifest by the violent agitation and rising and falling of the water in the gauge, and also the muddy appearance of the water, and the great quantity of particles of sediment contained in it that have been brought up from the lower part of the boiler by the violent ebullition of the water. *Priming* may and does go on unseen, but it can be discovered by the white appearance of the steam as it issues from the exhaust-pipe; as saturated steam, or steam containing water, has a white appearance and descends in the shape of mist, while dry steam has a bluish color, and floats away in the atmosphere. *Priming* also makes itself known by a clicking in the cylinder, which is caused by the piston striking the water against the cylinder-head at each end of the stroke.

IT has been too much the custom heretofore for owners of Steam-boilers to disregard the advice and suggestions of their own engineers and firemen, even though men of intelligence and experience, and to be governed entirely by the advice of self-styled experts and visionary theorists.

INCRUSTATION IN STEAM-BOILERS.

All natural waters contain more or less mineral matter. This is acquired by contact with the earth's surface, and by percolation through the soil and rocks. It consists principally of carbonates of lime and magnesia, sulphate of lime, and chloride of sodium, in solution, and clay, sand, and vegetable matter, in suspension. The many other saline ingredients found in various waters exist in very small proportions, are generally very soluble, and, therefore, have no relation to the utility of water in boilers. Of the above-mentioned salts, the carbonates of lime and magnesia are only soluble when the water contains free carbonic acid — consequently, the waters of rivers, lakes, etc., contain them in less quantities than those of wells, springs, and creeks, owing to the precipitation caused by the spontaneous evolution of the solvent on exposure to air, heat, and light.

Our American rivers contain from two to six grains of saline matter per gallon, in solution, and a varying quantity in suspension, generally exceeding ten grains. Well and spring waters hold but little in suspension, but a quantity of the dissolved salts, varying from ten to six hundred and fifty grains in the gallon. When such water is boiled, the carbonic acid is driven off, and the carbonates, deprived of their solvent, are rapidly pre-

cipitated in a finely-crystallized form, tenaciously adherent to whatever they may first fall upon. Sulphate of lime requires five hundred parts of water for its solution, and, as the water evaporates, supersaturation occurs, and the salt is precipitated in the same form and with the same adherent quality as the carbonates. Chloride of sodium, and all the other more soluble salts, are precipitated by the same process of supersaturation; but, owing to their greater solubility, much more evaporation is required. All suspended matter gradually tends to subside.

This combined deposit, of which the carbonate of lime usually forms the greater part, remains adherent to the inner surface of the boiler, undisturbed by the force of the boiling currents. Gradually accumulating, it becomes harder and thicker, till it is as dense as porcelain, though tougher, and at length may obtain such a thickness as to prevent the proper heating of the water by any fire that can be placed in the furnace.

The high heats sometimes necessary to heat water through thick scale, will sometimes convert the scale into absolute glass, by combining the sand with the alkaline salts composing it. The evil effects of the scale are due to the fact that it is relatively a non-conductor of heat. Its conducting power, compared with that of iron, is as 1 to 37.5. Consequently more fuel is required to heat water in an incrusted boiler than in the same boiler if clean. A scale $\frac{1}{16}$

inch thick will require the extra expenditure of 15 per cent. more fuel. This ratio increases as the scale is thicker. Thus, when it is $\frac{1}{4}$ inch, 60 per cent. more fuel is needed; $\frac{1}{2}$ inch, 150 per cent., etc.

Abstractly, then, to raise water in a boiler to any given heat, the fire-surface of that boiler must be heated to a temperature according with the thickness of the incrustation, in an increasing ratio. To illustrate: — To raise steam to a pressure of 90 pounds, the water must be heated to about 320° F. In a clean boiler of $\frac{1}{4}$ inch iron, this may be done by heating the external surface of the shell to about 325°. If $\frac{1}{2}$ an inch of scale intervenes between the shell and the water, such is its non-conducting power that it will be necessary to heat the fire-surface to about 700°, almost low red heat. Now, the higher the temperature at which iron is kept, the more rapidly it oxidizes, and, at any heat above 600°, it very soon becomes granular and brittle, and is liable to bulge, crack, or otherwise give way to the internal pressure. This condition predisposes the boiler to explosions, and makes necessary expensive repairs. Again, it is readily seen that the presence of scale renders slower and more difficult the raising, maintaining, and lowering of steam.

To obviate the evils arising from incrustation, many methods have been devised, and various mechanical contrivances have been introduced, intended to intercept the precipitated saline matter from the supply-water on its passage through the

heating apparatus. Straw, wood, charcoal, etc., have been introduced for this purpose; but such substances, however, only partially fulfil the purpose, since they only intercept a portion of the carbonates and suspended matter. The soluble salts all pass on into the boiler, and a great portion of the dissolved carbonates also, which cannot be precipitated during the short passage through the heater. The scales form more slowly, but as surely. It is impossible to make such contrivances completely efficacious. No mechanical arrangement will suffice. Even picking, scraping, and cleaning, when it can be resorted to, only partially succeed.

PREVENTION AND REMOVAL OF SCALE IN STEAM-BOILERS.

The pick, scraper, and hammer have hitherto been the means most generally employed for the purpose of removing scale and deposit, and although such instruments are dangerous tools in the hands of inexperienced persons, yet they are the only practical means of removing hard thick scale when it becomes firmly attached to the crown-sheets and other exposed parts of the heating-surface. Another plan to remove scale is to produce a sudden heat by a train of shavings in the flues and fire-box when the boiler is cold; the expansion of the metal cracks the coating, and is supposed to remove it in sheets of

greater or less size. This method works tolerably well, but cannot be relied on in all cases; it is also dangerous, as being liable to burn the boiler.

Almost every engineer has his own remedy for removing scale, among which may be mentioned slippery-elm bark, flax-seed, bass-wood, oak-blocks, witch-hazel, pork, coal-oil, buckwheat, Indian meal, mahogany sawdust, molasses, with a great variety of galvanic batteries and anti-crustators; but, strange as it may seem, the solvents and batteries that produced quite satisfactory results in some boilers totally fail to give any relief in others in the same neighborhood, using precisely the same water, and worked under similar conditions. This failure may not in all cases be due to the worthlessness of the article, but rather to the varying circumstances under which it is used, which include the character of the water, the design and construction of the boiler, the pressure and temperature, care and management, with a great variety of other features. It is nothing uncommon to find men engaged in the sale of anti-crustators, exhibiting large pieces of scale, sometimes two inches thick, which were removed by their nostrum. This only exhibits another proof of ignorance on the part of the party exhibiting it, as no purgative, solution, battery, or anti-lamina, could remove such a deposit; such enormous scales can only be thrown off by the expansion of the plates to which they become attached, as when the scale

becomes of an extraordinary thickness, it prevents the water from coming in contact with the furnace or boiler-sheets, as the case may be; the result of which is that the fire on the opposite side expands or bulges the plate or seam to such an extent that these enormous chunks of deposit are cracked or thrown off, and as a refutation of the claim that they were dislodged by the compound, powder, or battery, it will be found on examination that they are just as hard and flinty as the pieces that still adhere to the same plates. The question now comes up how could they have been dislodged, cracked, or thrown off by the article used for their removal, unless the scale was either softened in the first place, or unless the solvent prevented the water from coming in contact with the iron. This latter condition would admit of the iron being expanded to its utmost limit, a proceeding well known to involve very great risk. A very noticeable feature in connection with the sale of solvents, to prevent and remove scale from steam-boilers, is that the parties who manufacture or sell them set up precisely the same claims, and on examination of their certificates, it will be noticed that they all have recommendations from the same parties, which go to show that each one superseded all the rest.

It may be stated, without any fear of contradiction, that not one of the purgatives, antilaminas, powders, solutions, or batteries in use will give satisfactory results in all cases.

Now it must not be understood by this, that the writer wishes to discourage the use of solvents for the prevention and removal of scale; the fact is quite the reverse, as his own experience has been that some of the compounds now in use for this purpose have behaved very well. There is no mystery connected with the prevention of scale in steam-boilers, as six minerals, viz., sulphate of lime, phosphate of lime, carbonate of lime, magnesia, silica, and alumina, form the basis of fresh-water incrustation.

An analysis of sea-water shows it contains the following ingredients in different quantities: chloride of sodium, chloride of potassium, chloride of magnesium, bromide of magnesium, sulphate of magnesia, sulphate of lime, and carbonate of lime, etc., and any ingredient or compound that will neutralize these salts and prevent them from forming into a hard, glassy scale, until they can be blown or washed out, will do all that can possibly be accomplished in this connection, as, while it is retained in the shape of soft slush, or sludge, there is not much danger of the plates being burned through.

In boilers fed with water containing corrosive impurities, together with matters that form a thick incrustation, the damage that would be done may, to a great extent, be prevented by using some reliable solvent or compound. Catechu, nutgalls, and other astringents containing tannic acid, have been

found effective in preventing and removing incrustation. The tannic acid decomposes the lime-salts and forms tannate of lime, which is insoluble at first, and forms a scum, which should be removed by surface blowing off. The remaining soluble constituents should also be blown off frequently, as their concentration is liable to tell severely on the iron, unless the acids be neutralized by some compound purposely introduced. Hemlock, oak, log-wood, basswood, and mahogany sawdust are frequently used for the prevention of scale with varying results, as the tannic acid which these woods contain has a tendency to mix with the scale-forming ingredients, to render them more light and porous, and consequently to prevent them from forming in hard, solid masses; but, for want of any accurate knowledge of the quantity which should be introduced, they, in a majority of cases, fail to give any relief.

Zinc, in different forms, is frequently used as an anti-crustator in steam-boilers, but its action depends wholly on the character of the water; if it contains a sufficient amount of acid, a voltaic battery is formed between the iron of the boiler, the zinc, and the acid in the water; but if the water contains no acid, the zinc remains inert, and has no effect whatever on the scale; but it never fails to inflict permanent injury on the boiler connections, pumps, and steam-cylinder.

But even when the most efficient solvents are

used, it is necessary, at short intervals, to remove the accumulations from all accessible places, by blowing out, washing, scraping, etc. If the water is allowed to remain in the boiler until cold before cleaning, a great portion of the accumulations may be removed by means of brooms and scrapers, or be washed out with hose; but if the boiler is blown out under pressure, and the scale allowed to bake on the surface of the different parts of the boiler, it will be found difficult, if not impossible, to remove it.

As before stated, what is needed to render efficient and permanent relief is an article that will attack the scale, render it porous, and destroy the affinity between it and the iron, without any injuries to the latter, and will hold the minerals and ingredients, which are passing in with the feed-water, in the form of slush or sludge, until they can be blown out. G. W. Lord, a practical manufacturing chemist of Philadelphia, who has been, at various times, connected with many mechanical enterprises in this country, the West Indies, and South America, has succeeded, by experiment and observation, in producing an article—Lord's patent boiler compound—which has been in use over eight years in all parts of the United States, Canada, South America, Mexico, and Cuba, under the most varying circumstances, and in all cases with satisfactory results. The manufacturer and patentee can produce more than ten thousand testimonials of its efficiency from engineers

and steam-users. It neutralizes mine and mineral waters, which contain lime, iron, sulphur, and carbonates, destroys their affinity, and renders them simple and harmless. It not only prevents the formation of new scale, but decomposes the old and converts it into a soluble sediment, which may be blown out every day. It contains no acid which has any injurious effect on the iron of the boiler, — evidence of which may be found in the fact that the manufacturer, some years ago, filled several thousand vials with a solution of his compound, in which were placed a quantity of bright iron turnings and small pieces of steel wire, which appear as bright as the day they were immersed in the solution, one of which will be sent to any one who feels incredulous on the subject. Lord's compound gives relief in all cases when used according to directions. Parties wishing to test its efficiency should address GEO. W. LORD, Philadelphia, Pa.

SALTING MARINE BOILERS.

The term "salting," when used in relation to marine boilers, means that, in consequence of the boilers not being regularly blown out, the water becomes saturated to such an extent as to cover the plates with a heavy coating of salt, which renders them liable to bulge, crack, and burn through, besides inducing a great expenditure of fuel. Salt-water, at the usual density, contains $\frac{1}{32}$ of its weight of salt; consequently, if one pound of salt enters the boiler with every 32 lbs. of water, and 16 lbs. of that water be evaporated, the one pound of salt remains in the proportion of 1 : 16. Again, if $\frac{1}{2}$ of the 16 lbs. of water remains to be evaporated, the one pound remains in the 8 lbs. of water. Now, if these 8 lbs. of water were blown out of the boiler, the salt would go with it; and so long as that proportion is carried out, the saturation cannot exceed $\frac{4}{32}$; from which it is clear that, to keep water at $\frac{4}{32}$, one-fourth must be blown out; one-third at $\frac{3}{32}$, and at $\frac{2}{32}$ one-half of the water used for feed must be blown out.

The meaning of the term saturation, in its relation to the water of marine boilers, means the quantity of salt it contains per gallon. Saturation at $\frac{1}{32}$ means 4 oz. salt to one gallon fresh water; $\frac{2}{32}$, 8 oz. salt to one gallon water; $\frac{3}{32}$, 12 oz. salt to one gallon water, and so on. In carrying the water at $\frac{3}{32}$, twice as much is converted into steam as is blown

off. At $\frac{2}{3}\frac{2}{3}$, the water blown off and that converted into steam are equal. At $1\frac{3}{3}\frac{1}{2}$, the water converted into steam equals $\frac{3}{4}$ of the water blown off.

The annexed table shows the method of regulating the saturation, 600 gallons of water, which is supposed to contain 7200 oz. of salt, being made the basis of the calculation.

	Water in Gallons.	Salt in Ounces.	
	600	7200	
Blown out	200	2400	
Fed in at $\frac{1}{3}\frac{1}{2}$ to make up for deficiency .	400	4800	
	200	800	
	600	5600	
	200	steam	$\frac{1}{3}$ evaporated.
	400	5600	
Fed in	200	800	
	600	6400	
	200	steam	$\frac{1}{3}$ evaporated
	400	6400	
Fed in	200	800	
	600	7200	

The following calculation shows the loss induced

by blowing off as well as the gain derived from fresh-water condensers, providing they are tight and the condensation of the steam be perfect. The degrees of heat imparted to the water converted into steam are the total heat of the steam minus the degrees of heat in the feed-water. The heat lost by blowing off is the difference between the heat of the feed-water and the sensible heat of the steam.

Rule for finding the percentage of loss induced by blowing off to prevent saturation.

Multiply loss by blowing off by 100, and *divide* the product by the total degrees of heat imparted to the water plus the heat lost by blowing off. (Observe that for $\frac{3}{3\frac{2}{}}$ twice as much water is converted into steam as is blown off. For $\frac{3}{3\frac{2}{}}$, the amount is equal. For $\frac{1\frac{3}{4}}{3\frac{2}{}}$, the amount is $\frac{3}{4}$, and so on.) The result is the percentage of loss.

Example.—$\frac{3}{3\frac{2}{}}$.

Feed-water, 110°; total heat, 1193·45°; sensible steam, 260°.

260° — 110° = 150° heat lost by blowing off.

1193·45° — 110° = 1083·45° total heat.

1083·45° × 2 = 2166·9° + 150° = 2316·9° total heat imparted, and loss by blowing off.

(150° × 100) ÷ 2316·9° = **6·47 per cent. of heat lost by blowing off.**

TABLE

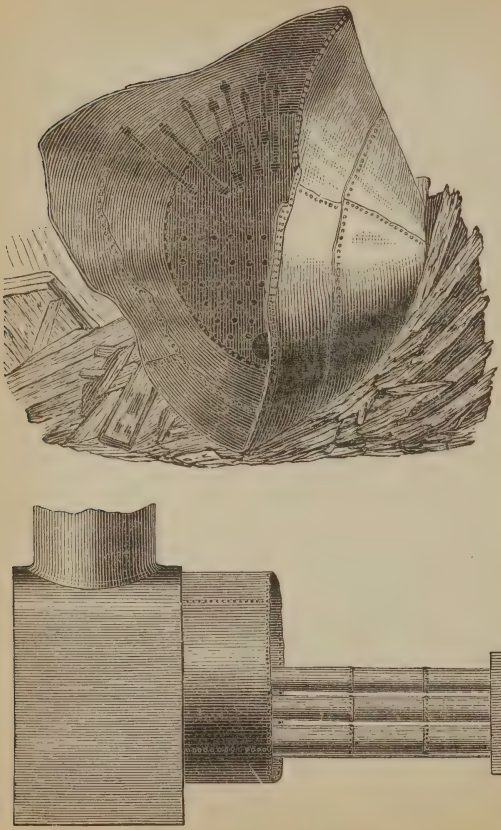
SHOWING THE PROPORTION OF SALT IN THE WATER OF DIFFERENT SEAS.

	PARTS IN 1000.
Baltic Sea	6·66 = $\frac{1}{152}$
Black Sea	21·66 = $\frac{1}{46}$
Arctic Sea	28·30 = $\frac{1}{35}$
Irish Sea	33·76 = $\frac{1}{30}$
British Channel	35·50 = $\frac{1}{28}$
Mediterranean Sea	39·40 = $\frac{1}{25}$
Atlantic at Equator	39·42 = $\frac{1}{25}$
South Atlantic	41·20 = $\frac{1}{24}$
North Atlantic	42·60 = $\frac{1}{23}$
Dead Sea	385·00 = $\frac{1}{2\frac{1}{3}}$

TABLE

SHOWING THE BOILING-POINT OF SALT-WATER AT THE DIFFERENT DEGREES OF DENSITY WHEN THE BAROMETER STANDS AT 30 INCHES.

	SATURATION.	BOILING-POINT
Fresh-water	.....	212 ° Fah.
Sea-water	$\frac{1}{33}$	213·2 "
"	$\frac{2}{33}$	214·4 "
"	$\frac{3}{33}$	215·5 "
"	$\frac{4}{33}$	216·7 "
"	$\frac{5}{33}$	217·9 "
"	$\frac{6}{33}$	219·1 "
"	$\frac{7}{33}$	220·3 "
"	$\frac{8}{33}$	221·5 "
"	$\frac{9}{33}$	222·7 "
"	$\frac{10}{33}$	223·8 "
"	$\frac{11}{33}$	225·0 "
"	$\frac{12}{33}$	226·1 "



EXPLODED BOILER OF THE FERRY-BOAT "WESTFIELD."

STEAM-BOILER EXPLOSIONS.

That the use of steam-power is fraught with danger is only too well known; the extent of the danger, however, as indicated by the number of boiler explosions every year, and the loss of life and property entailed, is but vaguely appreciated by the public. No official record is kept of such accidents, and only those of exceptional interest are reported in the newspapers. Even in such cases as are reported, it is almost impossible to ascertain their true cause, as there is seldom a unanimous opinion on the part of the experts who examine into the causes after the event; besides, there are a great many people who think they know something that will explain the cause of these fearful accidents, but, for some reason or other, their fine-spun theories have not been of any practical value. This doubtless arises from the fact that the conditions under which boilers are used, and the causes of their explosions, are very imperfectly understood by any one except those who have devoted time, thought, and study to their construction, care, and management.

Until quite recently, boiler explosions were attributed to one cause only, namely, an insufficiency of water; and this, in turn, was attributed to the carelessness of the attendant who had charge of the boiler. The boiler was iron, and, of course, it would not, or could not, explode if the vagabond fireman

had not let the water get low. The boiler might, in the first place, be made of an inferior quality of iron; might be constructed in the most bungling manner; the fittings might not only have been of the most inferior kind, but inadequate in every respect. In fact, it might be burned, banged, abused, or crystallized through excessive firing, or it might be cracked, patched, corroded, and taxed beyond its strength; and when patience ceased to be a virtue, it exploded. It was sure to bring down the censure, if not the vengeance, of the community on the devoted head of the unfortunate engineer or fireman; and if, perchance, his life was saved, he was sure to be ostracized and driven out, as though it were, from the face of the Lord. Strange as it may seem, this monstrous belief was not confined to timid people alone, but was entertained very largely by a class of men styling themselves scientific experts. Of course, in the face of such ignorance and stupidity, it would be useless to attempt to prove that some of the most destructive explosions that ever occurred in this country took place when there was a sufficiency of water in the boiler.

Another of the stereotyped causes of explosion was tampering with the safety-valve. That adjunct of the steam-boiler might be out of all proportion; it might be miserably constructed; in fact, it might be an unsafety-valve instead of a safety-valve — but what difference did that make when the boiler ex-

ploded? No one took interest enough in the matter to ascertain its proportions, or the manner in which it was fitted, so that the blame, if blame there was, might rest where it rightfully belonged, viz., on the party who attached such an abortion to the steam-boiler. All cheerfully united in cursing the fireman if living, and blasting his memory if dead. Verily, those who chose the care and management of the steam-boiler as a calling in the past, as well as those who intend to do so in the future, ought to feel grateful to the men who stripped boiler explosions of the mystery that so long enshrouded them, and attributed them to their real causes.

More recently, the theory that electricity was an active agency in steam-boiler explosions was quite rife; but Faraday and other eminent chemists proved conclusively that the development of electricity in the steam-boiler, if such a phenomenon could at all occur, would be due solely to the friction of the steam against the sides of the vessel; that the presence of electricity would be more likely to occur in the steam-pipe or in the steam-cylinder than in the boiler, and that all the experiments, investigation, and researches fail to discover the presence of electricity in steam. Even if it were a fact that the presence of electricity did actually exist in steam, how was it to accumulate? it certainly could not be done when the boiler was not in use, as there would be no friction to create it; and when the boiler was in use,

if such a thing could exist, the electricity would escape through the safety-valve and steam-pipe, or any of the openings, with a velocity more than one million times faster than steam at two hundred and forty pounds to the square inch. Besides, boilers and their connections are conductors, the same as lightning-rods; and if electricity existed in the boiler, it would soon find its way to the ground.

Explosive Gases.— This theory was, in its turn, urged as one of the main causes of boiler explosions, and it was claimed that large bodies of steam were decomposed by being brought in contact with red-hot plates, and that gas was formed with such rapidity and elastic force that no boiler structure was sufficiently strong to withstand it. But it was shown by thousands of practical experiments that only a very small quantity of steam could be decomposed by being brought in contact with the parts of steam-boilers most likely to become heated; and that even then it would not be dangerous, as the hydrogen is not explosive, unless mixed with its equivalent of oxygen, when it would have to be ignited with a spark to produce explosion. Again, assuming that nearly all the steam can be decomposed, the hydrogen would only burn quietly in the presence of oxygen, as it becomes liberated on the red-hot surface of the plates and fails to produce an explosion. But to take the extreme view of the case, assuming a sudden and perfect union of the gases to take

place, it would still be difficult to see how an explosion could take place, as neither the volume nor pressure would be increased.

Concussive Ebullition. — Then the phenomenon termed concussive ebullition was advanced as a cause of boiler explosions. This theory was founded on the experiments of Dufour, who claimed that by suspending drops of water in heated oil, the temperature of the water might be raised considerably above the boiling-point without the formation of vapor, but that if a bubble of air or a particle of any porous substance was placed in contact with the water a burst of vapor immediately occurred. Now if this theory should be shown to be correct, sensible people would be at a loss to know what relation or what similarity of conditions can exist between drops of water suspended in oil and a steam-boiler in ordinary use. It was also claimed that the presence of oil in steam-boilers would cause them to explode; but this theory lost much of its weight from the fact that oil is frequently used for preventing incrustation, and that the boilers in which it is used do not explode. It is also well known that oil is very liberally used in the making of steam-boilers, and that there is hardly one that has not had more than a gallon of oil smeared over its surface in the different processes of manufacture.

Spheroidal Theory. — The spheroidal theory is the so-claimed tendency of water, when thrown upon

highly heated plates, to assume the spheroidal condition, and to evaporate suddenly when the temperature is sufficiently lowered. The exact application of this theory is by no means clear, and the assumed delay of the water in evaporating is antagonistic to the sudden evaporation from the overheating theory, as it is difficult to see how the evaporation of a large quantity of water in an ordinary boiler could be delayed (as is assumed in this theory) without reducing the temperature of the water below that sufficient to produce an explosion. It is well known that water in this state evaporates very slowly, and this has been attributed to the supposed fact that the heat was transmitted through the spheroids; but Boutigmy attributes it to the reflection of heat from their surfaces, showing that they do not absorb heat.

All the foregoing magnificent theories have been disproved through the operations of the Hartford Steam-Boiler Inspection and Insurance Company. Proof of this is found in the fact that whenever manufacturers and steam-users place their boilers in the care of this Company they are sure to receive immediate and full protection from steam-boiler explosions. As it is noticeable that the electricity immediately gives out, that the drops of water fail to suspend in heated oil, or even form into spheres and roll over the surface of the plates like spinning-tops, that the gas fails to generate in volumes that would place a Wilcox's fire-annihilator in the shade,

and that the water refuses to thump against the sides of the boiler, when the intelligent and experienced inspector comes to do so with his hammer and chisel, he would be very likely to say that either such theories or the plates were a "little too thin," or perhaps both. To compensate for the absence of so many splendid phenomena, there is always sure to be an immense discovery of broken braces, cracked seams, bulged plates, distorted crown-sheets, defective steam-gauges, and inferior safety-valves.

The principal causes of explosion, in fact the only causes, are deficiency of *strength* in the shell or other parts of the boilers, *over-pressure*, and *over-heating*. Deficiency of strength in steam-boilers may be an original defect, arising in the material or workmanship at the time of construction, or it may be due to deterioration from use, to ordinary wear, or to injuries arising from mismanagement, want of attention, and repairs, etc. It often happens that boilers are deficient in strength for the pressure they are intended to bear, and no accumulation of pressure beyond this is necessary to bring about their destruction. Deficiency of strength arising from bad workmanship is the most difficult to discover, and not unfrequently escapes the closest scrutiny, more particularly so in the case of flue, tubular, and locomotive boilers, as their examination is attended with certain difficulties.

Over-pressure may be caused by the safety-valve

being recklessly overweighted, by the sticking of the valve on its seat, by the inadequate size of the communication between the boiler and the valve, or by an incorrect or worthless steam-gauge. Boilers are frequently found running at a pressure which is regarded as perfectly safe, but when the gauge is examined and compared with one known to be correct, it is found to be 10, 20, or even, as is sometimes the case, 50 pounds out of the way. If a boiler supposed to be running under a pressure of 80 pounds is found, in consequence of an unreliable steam-gauge, to be actually running at a pressure of 120 to 130 pounds, the limit of safety may have been passed, and an accident is imminent, which may occur at any moment.

Over-heating induced by excessive firing is no doubt the cause of many explosions, and most frequently occurs when the boiler is too small for the engine, or incapable of furnishing the required amount of steam, as the intensity of the fire necessary to generate the desired quantity of steam has a tendency to repel the water from the plates. The same effect may be produced when there is a great disproportion between the grate- and heating-surfaces, or where the heat from a large grate is concentrated on a small space. Under such circumstances, the heat is delivered with such intensity as to lift the water from the surface of the iron, thereby exposing it to the direct action of the fire. Explosions occur-

ring from excessive firing are in all cases the result of avarice, ignorance, or a want of skill in the care and management of the steam-boiler. Over-heating may be caused by the accumulation of hard, solid incrustation adhering to the parts most exposed to the direct action of the fire, or it may be due to shortness of water, which may result from leakage of the valve or stop-cock, to a failure in the supply-pipe, or neglect to turn it on at the proper time or in sufficient quantity.

A steam-boiler may be well designed, made of good material, and of first-class workmanship, and yet in a few months after being put under steam it may explode with terrible effect. On examining into the cause of the explosion, it may turn out that the water which was used made a heavy deposit; that the boiler had not been cleaned out since it was put in use; that the fires had been fiercely urged, and the water driven from the surface of the iron; as a result, the life had been entirely burnt out of the sheets directly over and around the fire, thereby weakening the boiler and putting it in a dangerous condition. That the sudden heating or cooling and oxidation of the boiler induce great deterioration of strength has been proved by experience. Defects in the material, as blisters, lamination, arising either from their inferior quality or want of care in the manufacture, are other sources of weakness in steam-boilers.

A great deal more might be written on this subject if needed, but suffice it to say that there is no mystery about steam-boiler explosions; they are all regulated by cause and effect; and it will be found, on investigation, that seven-tenths of all the boiler explosions that occur yearly in this country might be traced to some sufficient cause, were all the facts known. Even if there is some apparent mystery connected with boiler explosions in some instances, it will vanish before sound and careful investigation. The solution may involve the examination of a great number of boilers and extend over years, but the greater the number examined, with their particular defects understood and explained, the greater will be the fund of information from which to draw conclusions. No amount of theory will explain the different causes of explosions, as that can only be determined by a full comprehension of the circumstances under which they occurred, which involves the quality of the material of which they are constructed, character of workmanship, form or type of boiler, setting, attachments, properties of water used, kind of fuel, age, treatment, and skill employed in the care and management. These are the vital points to be considered in order to arrive at any approximate solution of the cause or causes of steam-boiler explosions.

The sooner steam-users and engineers discard all theories in connection with steam-boiler explosions,

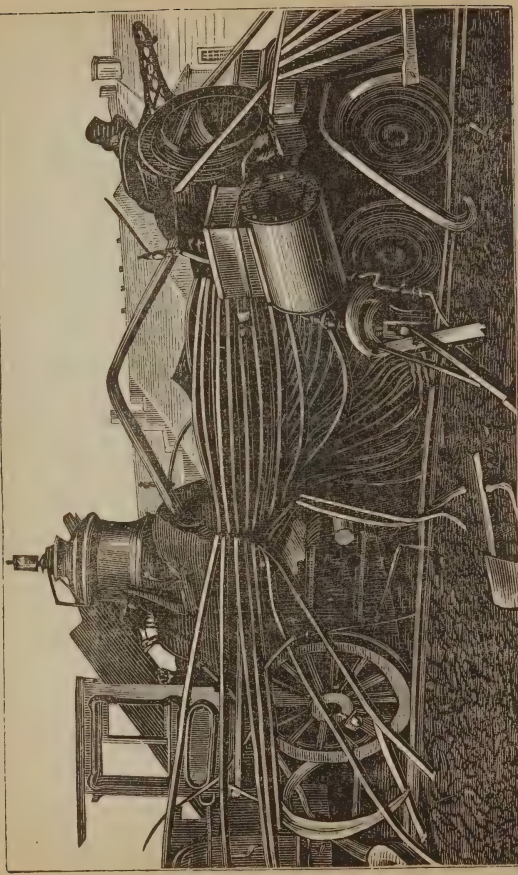
and come to the conclusion that when a boiler explodes one of two things is certain — either that the pressure was too great for the boiler, or that the boiler was not equal to the pressure; that it gave way in the weakest place, and that the strength of any machine (the steam-boiler included) must be measured by its weakest point, and that the sooner this principle is universally recognized the better it will be for every steam-using community. A weak spot, a flaw, or a crack in a boiler does not improve by use, and when any machine breaks down at a point which shows that it must have been weak for a long time, no one thinks of going into a long discussion or explanation of the mysterious agencies which were suddenly brought to bear on it and cause it to break. Not so, however, with a steam-boiler; it may have been burned, corroded, and cracked for years, and when at last it explodes there are always to be found those who wish to involve the whole thing in mystery and tell how it must have occurred, who are always unable to tell how it might have been prevented.

Within the past eight years, mainly through the operations of the Hartford Steam-Boiler Inspection and Insurance Company, steam-boiler explosions have been stripped of the mystery in which visionary theorists had so long enshrouded them, and the belief in such heresy as mysterious steam-boiler explosions is principally confined to those who are

incapable of or unwilling to be convinced, even when the facts are laid before them. The class of persons, of all others, that ought to encourage such theories, and take refuge behind them, when called upon to pay damages in case of accident, are those who discard such theories when accounting for boiler explosions, and the correctness of their views is sufficiently attested by the almost entire absence of serious accidents in connection with the thousands of boilers of all sorts and conditions that are or have been in their care for several years past.

Few have any idea of the extent to which steam is used in our large cities, or of the risks to which even those who have no interest in the boilers, and who are not connected in any way with the business in which they are used, are exposed. In almost every building along our principal thoroughfares may be found a large boiler, used for heating purposes or for furnishing power, which is concealed from public view. It is only when the public are startled by an explosion, and by the death or injury of innocent persons, that the true condition of things is revealed, and that the dangers incurred by every passer-by are exposed.

THE opinions of wise men, who are willing to investigate for the purpose of gaining and giving information, are entitled to due respect and consideration. But when theories and opinions are promulgated that have no truthful basis upon which to rest, and which seem to have no end save that of exalting the promulgator, it is the duty of those who have had practice and experience to counteract such influences, and show how much labor can be expended in mystifying and clouding a subject which might otherwise be comparatively simple.



EXPLODED BOILER OF THE LOCOMOTIVE "CHARLES WILLARD."

EXPERIMENTAL BOILER EXPLOSIONS.

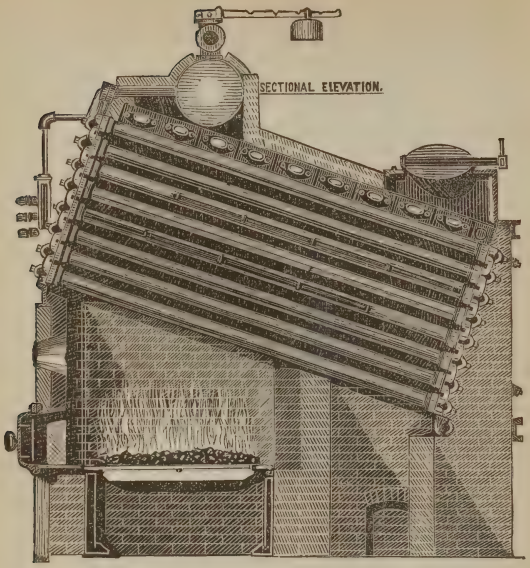
Several attempts have been made, and large sums of government money expended, to ascertain the cause of steam-boiler explosions by experiment; but such experiments have failed to shed any light on the subject, as they must ever do, in consequence of the circumstances under which boilers are made and used being so different. Take, for instance, two boilers of the same dimensions in every respect, and of the same material and workmanship, to be used in different parts of the country and under entirely different circumstances. One may explode with disastrous effects, while the other may remain perfectly safe and sound. Now what relation can be established between the danger or safety of either, unless all the circumstances connected with their care and management be known, viz., properties of water, character of the setting, condition of the boiler, care and management, etc. A boiler of a peculiar type may be selected for the purpose of testing what pressure it would take to burst or explode it.

The first thing to be done in such a case would probably be to see that the joints were all steam- and water-tight, and that the braces were all taut, and everything restored as nearly as possible to its original condition. The explosion may establish the fact that the boiler sustained a pressure of two or

three hundred pounds to the square inch before giving away. Now, perhaps, there may be located in the same neighborhood a boiler of the same type, made by the same manufacturer, of the same thickness and brand of iron, and by the same mechanics; but it may have some inherent defect, due either to the material or the workmanship. It may have been badly cared for, burned, bulged, crystallized, cracked, or corroded; then, if it should explode, what relation would it bear to the other, save simply in type? What criterion would it establish by which to determine the safe working or bursting pressure of all classes of boilers, or even those of the same type? The following instance came to the knowledge of the writer, which goes to show how futile any attempt must ever be to establish the cause of steam-boiler explosion by experiment. An engineer undertook to apply the hydrostatic test to the boiler in his charge; and, to accomplish his object, he placed a quantity of grate-bars on the lever of the safety-valve, and by means of a force-pump raised the cold-water pressure to one hundred and twenty pounds to the square inch, without the boiler showing any signs of weakness or leakage, although it had been in use nine years. The test was considered satisfactory; the water was then run down to the proper level, the fire started, and it was only when steam blew off at the safety-valve that the engineer remembered that he did not remove the grate-bars from the

safety-valve lever. He then drew his fire, and allowed the boiler to cool, and when the grate-bars were taken down and weighed, it was ascertained that the boiler sustained a steam-pressure of three hundred and seven and one-half pounds to the square inch.

Another boiler of the same type, located in the same neighborhood, built by the same manufacturers, and as nearly alike in every respect as possible, showed signs of leakage when only two years in use; but, as the cause of the leakage was concealed under a mass of masonry, it was impossible to ascertain what the nature of the defect was. An experienced boiler-inspector was called in, and, after removing a portion of the brickwork by which the boiler was enveloped, he discovered that the material was cracked through between thirteen rivet-holes in one of the seams a little below the water-line, and that the heads of three of the rivets in that part of the seam that was sound had dropped off, in consequence of being cold-shutted in the process of riveting. Such a boiler would, in all probability, burst or explode under a pressure of less than one hundred pounds to the square inch, which goes to show that the cause of boiler explosions can never be determined by experiment. This can only be ascertained by a knowledge of all the circumstances connected with each individual case.



THE ROOT BOILER.

This boiler consists essentially of 80 wrought-iron tubes, 4 inches and 9 feet long. These tubes are set in brickwork, at an angle of about 30° from the horizontal. The tubes are connected together at the ends by a system of triangular plates and crowfeet. The boiler has a steam-drum 18 inches by $6\frac{3}{4}$ feet long. The superheating is effected in the upper portion of the boiler.

VAGARIES OF EXPERTS IN REGARD TO STEAM-BOILER EXPLOSIONS.

The boiler in a plaster-mill in Pennsylvania exploded, killing the fireman instantly, and it was on evidence at the inquest that the boiler was so located that it had no protection from the effects of the weather. It was not known to have been cleaned or examined for ten years. The steam-gauge got out of order and was allowed to fall into disuse, and the gauge-cocks became choked with mud. After the explosion, the safety-valve was picked up more than one hundred feet from where the occurrence took place, and it was so much corroded, that it became necessary to use a hammer to drive it from its seat. An expert was summoned to testify at the inquest, in order that the jury might be able to form their conclusion as to the cause of the fireman's death, and he stated that the air that afternoon was surcharged with electricity, and that that was undoubtedly the cause of the explosion; he was invited to examine the boiler and its attachments for the purpose of satisfying himself on the subject, but he declined to do so, stating that his mind was fully made up in regard to the cause of the explosion.

Two large steam-boilers in a cabinet manufactory in Philadelphia had but one safety-valve, which was located on a branch-pipe for the purpose of allowing a stop-valve to be placed between it and

the boiler, for the purpose of using one boiler at a time if desirable. On one occasion, when the engine was undergoing repairs, it became necessary to shut down this stop-valve; when everything was ready, in the absence of the regular engineer, one of the workmen was instructed to fire up with wood and shavings, and as all the means of escape for the increasing pressure was cut off, the boiler exploded, killing eighteen men and injuring two others so that they died soon afterwards. A noted expert was summoned before the coroner's jury to explain if possible the cause of the disaster, and he testified that there was a strong current of electricity passing between the poles that afternoon, and that its passage was probably obstructed by some dense clouds, which phenomenon was the cause of the explosion. He further stated that if the explosion had not occurred until an hour afterwards, he did not believe it would have taken place at all.

The owner of a planing-mill in Michigan, instead of employing a competent person to take charge of his engine and boiler, instructed any of his workmen who could find it most convenient to fire up, and run the engine. The water which was used in the boiler was taken from a mountain stream, and was so impregnated with lime that the pipes became choked, and the boiler became so coated with incrustation that it bulged and cracked in several places, and finally exploded, killing three men and frightfully

wounding five others. An expert was sent for in order that his testimony might shed some light on the cause of the explosion. He stated that there was an extensive belt of ozone extending over that section of the country, and that wherever the presence of ozone existed in the air boilers would explode, no matter how carefully they were managed.

At the investigation that followed the explosion on board the ferry-boat "Westfield," it was shown that the boiler was made of ¼-inch iron, and 120 inches in diameter. The safe working-pressure of such a boiler when new, according to Fairbairn, would be from 28 to 30 pounds per square inch. It was in evidence that, though the boiler had been in use twelve years, it was badly cracked and patched, and was carrying a pressure of 40 pounds to the square inch at the time of the explosion. Such a statement of facts would enable any intelligent mind to form a definite conclusion as to the cause of the explosion; nevertheless, an expert came forward and offered to explain the cause of the disaster, when, on being questioned, he stated that at the time of the explosion the boiler was full of inflammable gas, and when asked what kind of gas, he answered that it "might a' bin" oxygen.

Experts have always made it an object to mystify the cause of steam-boiler explosion, probably for the purpose of retaining the honor among their fellowmen of being looked up to as the only exponents of

a phenomenon which produces such disastrous results. They seem to imitate the ancient priests, both among the Jews and heathen, who were, from their ordinary duties, necessarily conversant with the generation of steam; but their knowledge of it was mainly exerted to delude men to idol worship and lock their minds in ignorance instead of to benefit and enlighten them.

DEFECTS IN THE CONSTRUCTION OF STEAM-BOILERS.

The following cuts illustrate some of the mechanical defects that impair the strength and limit the safety and durability of steam-boilers. All punched holes are conical, and unless the sheets are reversed, after being punched, so as to bring the small sides of the holes together, it will be impossible to fill them with the rivets. Fig. 1 shows the position of the rivet in the hole, without the sheets being reversed; and it will be observed that, as very little of the rivet bears against the material, the expansion and contraction of the boiler have a tendency to work it loose. It is apparent that such a seam would not possess over one-third the strength that it would if the holes in the sheets were reversed and thoroughly filled with the rivet, as shown in Fig. 2. Fig. 3 represents what is known in boiler-making as a blind-hole, which means that the holes do not come opposite each other when the reams are placed together for

FIG. 1.

FIG. 2.

FIG. 3

FIG. 4.

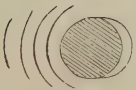


FIG. 5.

FIG. 6.

the purpose of riveting. Fig. 4 shows the position of the rivet in the blind-hole after being driven. It will be observed that the heads of the rivet, in consequence of its oblique position in the hole, bear only on one side, and that even there the bearing is very limited, and, through the expansion and contraction of the boiler, is liable to work loose and become leaky. Such a seam would be actually weaker than that represented in Fig. 1. Fig. 5 shows the metal distressed and puckered on each side of the blind-hole in the sheets, which is the result of efforts on the part of the boiler-maker, by the use of the drift-pin, to make the holes correspond for the purpose of inserting the rivet. Fig. 6 shows the metal broken through by the same means.

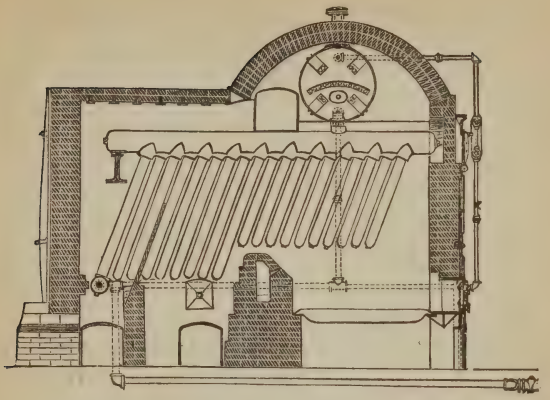
Now it will be observed that nearly all the above defects are the result of ignorance and carelessness, showing a want of skill in laying out the work, as well as a want of proper appliances for that purpose. The evils arising from such defects are greatly aggravated by the fact that they are all concealed, frequently defying the closest scrutiny, and are only revealed by those forces which unceasingly act on boilers when in use. Such pernicious mechanical blunders ought to be condemned, as they are always the forerunners of destruction and death. There can be no reason why boilers should not be constructed with the same degree of accuracy, judgment, and skill as is considered so essential for all other classes of machinery.

IMPROVEMENTS IN STEAM-BOILERS.

Until quite recently the steam-boiler has undergone very little improvement. This arose, perhaps, from the fact that men of intelligence and mechanical genius directed their thoughts and labors to something more inviting and less laborious than the construction of steam-boilers. Consequently, that branch of mechanics was left almost entirely to a class of men that had not the genius to rise in their profession or improve much in anything they attempted. As a result, ignorance, stupidity, and a kind of brute force were the predominant acquirements in the construction of the steam-boiler; but within the past few years this state of things has been changed, as some very important improvements have been made, not only in the manufacture of the material of which boilers are made, but also in the mode of constructing them. The imposing display of powerful and accurate boiler machinery shown at the Centennial Exposition in Philadelphia, is an evidence that the attention of eminent mechanics and manufacturers is directed to the steam-boiler, and that in the future its improvement will keep pace with that of the steam-engine.

Boiler-plate is now rolled of sufficient dimensions to form the reams for boilers of any diameter with only one seam, obviating the necessity of bringing riveted seams in contact with the fire, as was usually

the case in former times. In the manner of laying off the holes for the rivets, accurate steel gauges have taken the place of the old-fashioned wooden templet, thereby removing the evils induced by blind-holes, and obviating the necessity of using the drift-pin. So, also, in the method of bending the sheets to form the requisite circle—with a better class of machinery, the work is now more accurately performed. The old process of chipping is, in nearly all the large boiler-shops, superseded by planing the bevels on the edge of the sheet preparatory to calking. Recent improvements in "calking" have resulted in perfect immunity from the injuries formerly inflicted on boilers in that process. In most establishments of any repute in this country, riveting is done by machinery, which is (as is well known to all intelligent mechanics) very much superior to hand-riveting. It is only small shops that enter into rivalry to secure orders and build cheap boilers, using poor material and an inferior quality of mechanical skill, that use the same old crude appliances —in many cases the merest make-shifts—that were in use a quarter of a century ago, and constructed without regard to any of the rules of design that are considered so essential in appliances for the construction of all other classes of machinery.



THE ALLEN BOILER.

In this boiler the roof of the fire-chamber is made of nine cast-iron cylinders, each seven inches internal diameter and eleven feet long; and into each of these cylinders eighteen wrought-iron tubes, three and a half inches in diameter, are screwed, the lower ends being closed by plugs. These tubes hang down from the roof into the fire-chamber, and are set at an angle of about twenty degrees from the vertical; the lower end being farthest from the fire-door. The tubes over the fire are three feet two inches long, the rear ones are four feet five inches long. Steam-drums are arranged over the boiler.

EVERY Engineer should inform himself on the subject of the safe working pressure of Boilers, and when he finds the limit of safety has been reached, he should promptly inform his employer, and use his influence to have the Boiler worked within the bounds of safety.

CARE AND MANAGEMENT OF STEAM-BOILERS.

No class of men are entrusted with greater responsibilities, none hold in their keeping more important interests of life and property, than those having the charge of steam-boilers. A mistake in judgment at a critical point, or a careless neglect of duty, may cause, and has often resulted in, terrible destruction to life and property. The most skilful and best-informed engineers, and those best versed in steam matters, are the ones who most fully appreciate its dangers, and also the most willing to learn all they can relative to any new points of interest, danger, or safety.

In the management of steam-boilers there are certain rules that must be observed, and to insure faithfulness, the owners of boilers should secure the services of intelligent men — ignorance and carelessness have been the occasion of too many accidents, and great destruction of life and property has not unfrequently been the result of employing cheap help. In the care and management of steam-boilers, men should be employed who know at least something of the nature of the power with which they have to deal; men who understand the use of the various attachments on steam-boilers; men of good sound judgment who have, if not a thorough, at least a practical knowledge of the strength of iron, of its capabilities to resist pressure, and who know beyond

what limits they should not allow pressure to accumulate.

It will be poor consolation to the owner of a steam-boiler, after his property has been destroyed by a terrible explosion, to congratulate himself on the fact that he saved a few dollars a month in the wages of his engineer, by employing a careless or incompetent man. But if those who neglect and abuse steam-boilers were the only ones to suffer from explosions, carelessness and mismanagement would be less a matter of public concern; but when the lives of hundreds are often thus exposed to danger, it should be the aim of every steam-user to do his utmost to render the use of steam in his establishment safe, as after an explosion, where persons have been killed or maimed for life, the public verdict is very severe, and no right-minded man would wish to covet any man's experience or reflections who has laid himself open to public censure by neglecting to do what might have prevented so serious a disaster.

A very mischievous practice exists in various parts of the country in reference to starting fires under steam-boilers preparatory to raising steam. This duty is entrusted to ignorant watchmen, who are too often the agents of disaster. These men are instructed to light the fire at a certain hour, and comply with their orders without exercising the least judgment on the subject. Numerous instances are on record where watchmen have started the fires

under steam-boilers and raised steam before discovering that there was insufficient water in the boilers, thus incurring the risk of burning the boilers, if not actually ruining them. No persons ought to be permitted to meddle in any way with the steam-boiler, except those who are skilled in the management of them, and who are fully conversant with the properties of steam. Thousands of lives are lost and much valuable property destroyed through the ignorance of those left temporarily in charge of steam-boilers.

It may seem strange, but it is no less true, that, notwithstanding the numerous fatal explosions that have occurred, resulting from defects which could not have escaped the notice of a competent inspector, many of the users of steam-power appear to be indifferent as to the condition of their boilers. They would rather incur the risk of an explosion than stop their works one day in the year, that their boilers may be thoroughly examined. Even then many of them will not be at the trouble or expense of having the boilers properly cleaned and the flues swept, without which a satisfactory examination is impossible.

In the majority of cases boilers are not cleaned half as often as they should be. When the water is hard, and scale accumulates on the sides or flues of the boiler, solvents are very often resorted to to remove the scale. After the scale has been thrown down it is frequently allowed to remain there and

form a heavy conglomerate coating, which prevents the water from coming in contact with the iron, the result of which is that the parts of the boilers exposed to the direct action of the fire are cracked, bulged, or burned through. The yearly report of the Hartford Steam-Boiler Inspection and Insurance Company shows that nearly half of the whole number of defective boilers became so on account of incrustation and deposit of sediment; and, strange as it may seem, there were forty per cent. more dangerous cases from the deposit of sediment than from incrustation and scale.

The first duty of an engineer or fireman when he enters his boiler-room in the morning is to try the boiler gauge-cocks and ascertain if there is a sufficient supply of water. Many boilers have been badly injured from neglect of this precaution. Fires are often replenished, and when well started, attention is directed to the water in the boiler. If from any cause during the night the water has escaped, the result may be a burned sheet, or probably still more serious injury.

Too much reliance should never be placed on self-acting apparatus, such as gongs, floats, steam or alarm whistles, for regulating the height of the water in steam-boilers, as, even if they act with certainty, they provide only against one or two contingencies, while the dangers to which steam-boilers are exposed are numerous.

The glass water-gauge, though one of the simplest, most beautiful, and useful attachments of the steam-boiler, should not be relied upon altogether to show the level of the water in the boiler.

The gauge-cocks should be kept clean and in constant use, as they furnish the most reliable means of ascertaining the height of the water in a steam-boiler.

The furnace door should never be allowed to remain open longer than is sufficient to clean and replenish the fire, as the contraction of the tubes and flues, induced by the cooling down of the furnace, has a very mischievous effect on all parts of the boiler exposed to the cold draught.

The feed-water should be sent into the boiler as hot as possible, as, if it be forced in at a low temperature, it will impinge on that portion of the boiler with which it comes in contact, and, as a result of the continual expansion and contraction induced by the varying temperature of the water, the boiler is liable to crack and become leaky.

If, from neglect or any other cause, the water in the boiler should become dangerously low, the fire-doors and damper should be immediately thrown open, for the purpose of admitting the cold air to the heated plates, and the fire withdrawn as soon as possible. Under such circumstances no attempt should be made to introduce cold water into the boiler, or disturb the safety-valve, as either might be attended with disastrous results.

The safety-valve should always be moved before the fire is started to get up steam, for the purpose of ascertaining if it is in good working order. It should also be raised whenever the boiler is being filled with cold water in order to allow the air to escape, as air has a tendency to retard the influx of the water, and also to occupy the steam-room when steam is raised. Air also interferes with the uniform expansion of the boiler.

All new boilers should be thoroughly examined before being filled with water, to ascertain if there are any tools, wood, lamps, greasy waste, etc., left behind by the boiler-makers, that would be liable to be carried into connections or cause the boiler to foam.

In getting up steam in boilers just filled with cold water, or that have been out of use for some time, the fire should be allowed to burn moderately at first, in order to admit of the slow and uniform expansion of all parts of the boiler; as, when the fire is allowed to burn rapidly from the first start, some parts become expanded to their utmost limits, while others are as yet nearly cold, thereby subjecting the boiler to fearful strains, induced by unequal expansion and contraction, which frequently results in leakage, fracture, and sagging of the shell or flues.

When boilers are laid up, or out of use, even if it be for a few days, they should be opened, cleaned, and thoroughly examined, to ascertain if any of the stays or braces have become loose, slack, or disconnected.

Before being closed up, all gaskets for man- and hand-holes, and grummets for mud-holes, should be painted with a coating of black lead and tallow, to protect their seats from deterioration induced by the chemical action of the sulphur in the gum-packing, now so universally used for the joints of steam-boilers.

When the weight is once fixed on the lever of a safety-valve, at the right point to retain the safe working pressure, the extra length of the lever should be cut off.

The feed-supply and the firing should be as steady and as regular as possible, as frequent and extreme alterations of temperature, especially with boilers carrying a high pressure, or irregularities of any kind, have a very injurious effect.

Ashes should never be allowed to accumulate around the water-legs of fire-box boilers, or the water-bottom of any boiler, as wet ashes, like any other lye, corrodes, and eventually destroys the iron.

Boiler-flues should never be allowed to become choked with ashes, nor the shells to become coated with soot, as it very much impairs the efficiency of the heating surface and induces a wasteful consumption of fuel. The flues and tubes of boilers should be swept out at least once a week. This is a very important object in point of economy, as, when the flues become choked with ashes, it requires an extra expenditure of fuel to generate the necessary quantity

of steam. Care and attention to little matters in managing steam-boiler fires will not only add to the working age of a boiler, but save materially in the consumption of fuel.

Boilers should never be filled with cold water while they are hot, as it causes contraction of the seams and stays, often inducing fracture of stays or leakage in the seams and tubes. The tubes of boilers being generally of thinner material than the shell, cool and contract sooner. For this reason the boiler should never be filled with cold water while the tubes are hot.

When two or more boilers are connected by feed-pipes, the stop-valves on each should be shut off when not working, as the water is liable to escape from one to the other, on account of variation in the pressures; and as a consequence, when the water in one is up to, or even above, the proper level, the tubes or flues in the other are very often destitute of water.

When, in consequence of leakage, accumulations of salt occur in the flues or tubes of marine-boilers, they should be removed as soon as possible and the tubes thoroughly swept, or, if need be, bored out with a flue-scraper; otherwise the parts covered with the accumulation will be apt to be burned through. In some cases it is necessary to direct a steam-jet on the place affected for the purpose of softening the deposit.

When flues become so leaky that it is impossible

to make them tight in the tube-sheet by calking, this object can be effected by cast- or wrought-iron ferrules or expanders driven into the end of the tube. This arrangement, however, is only an alternative, as it interferes with the free escape of the gases from the furnace and diminishes the draught.

One of the most common causes of deterioration in steam-boilers, and also of leakage of the seams and under side, and at the junctions of the tubes and tube-sheets, is the reckless practice of blowing out the boiler while still hot and filling it again with cold water. Under such circumstances, the contraction of the crown-sheet, tube-sheets, and tubes is so rapid and unequal, that, if persisted in, the result is the ruin of the boiler.

When an engine is stopped, if the steam should increase to an excessive pressure, the safety-valve should not be moved, as any sudden release of the steam might be attended with risk: it is better to open the furnace door, cover the fire with fresh fuel and turn on the feed-water; this will have a tendency to lower the temperature and keep up the circulation in the boiler, so essential to safety when the steam is shut off and a hot fire in the furnace. Many boilers have exploded just as the engine was starting, after having stood still for some time; this arose, doubtless, from the fact that the plates directly around and in contact with the fire became overheated in consequence of the circulation becoming

enfeebled or entirely suspended after the steam was shut off. As soon as the engine was started and the pressure lessened, the water on the surface of the over-heated plates flashed into steam of tremendous elastic force.

When boilers are to be cleaned they should be allowed to stand for several hours and cool before the water is run out; the deposit of mud and scale will then be found to be quite soft, and can be easily removed or washed out with a hose from all accessible parts. There is a very erroneous impression existing among engineers and steam-users, that blowing out a boiler under a high pressure has a tendency to remove the mud or deposit; this, however, is a mistake, as the contraction of the different parts of the boiler, induced by so sudden changes of temperature, has a tendency to induce leakage of the seams and round the rivets and ends of the tubes.

It is a very general impression among engineers and firemen, and receives encouragement from those who sell nostrums for the prevention and removal of scale, that so long as the mud or deposit is retained in the soft or slushy state, it can do the boiler no harm. This is undoubtedly a mistake, as it retards the escape of the heat from the fire to the water, inducing over-heating, which is generally followed by cracking and blistering of the plates and leaking at the seams.

It is not uncommon in factories to have two

boilers for the same engine, in order that one may be out of use while the other is working; but, while this is an accommodation, it is not always economy, as boilers wear out faster when not in use, by oxidizing and corroding, than if moderately worked. It will be found more economical to work with extra boiler room than to have one or more standing idle, as it will tend to prevent priming; besides, the furnaces will be more economically worked with a thick fire than with a thin one, and more of the heat will be absorbed by allowing it to accumulate, thereby maintaining a high temperature in the furnace with slow combustion.

Never neglect to blow out, examine, and clean boilers when solvents are used to prevent and remove scale; because boilers under such circumstances require as much, if not more, care than if no solvent or compound is used, as all that can be accomplished at best by such agents, is to loosen and throw down the scale, which if not removed will be apt to form into a hard conglomerate on the bottom of the boiler, preventing the water from coming in contact with the iron; the result is, the plates are burnt through and the boiler permanently ruined.

IT is a matter of regret that, too often, firemen and engineers are laggards in the issues of that real intelligence which ought to be carried out as effective traits of character, indispensable to the credit of their profession. Too often a loose indifference to correct rules is displayed by them, which shows that they have failed to perceive their own advantages.

INSTRUCTIONS FOR FIRING.

In estimating the relative merits of different steam-engines, it is generally assumed that the fuel is burned under conditions with which the men who supply coal to the furnaces have nothing whatever to do. In short, that any man who can throw coal on a fire and keep his bars clean, must be as good as any other, however well qualified. But this conclusion is totally erroneous, as it is within the experience of nearly every engineer and steam-user, that many engines now in operation throughout the country consume twice as much fuel, per horse-power, as is required for those that are more economically managed.

The use of a more improved class of steam-engines involves the necessity of employing more skilful and careful attendants; not that the work is more difficult, as less coal has to be thrown into the furnace, but because a careless or unskilful fireman can counteract all the ingenuity displayed in the improvement, construction, and management of the engine. Consequently, every engineer should be required to prepare himself for the duties of his profession by commencing as a fireman; otherwise, he cannot be expected to be able to instruct his fireman in the manner of firing best calculated to insure the most satisfactory and economical results.

There have not been, heretofore, that attention

and thought devoted to the examination of the subject of the economy of fuel which the magnitude of the interest involved, and its importance, in a national point of view, render it worthy of. The saving of one pound of water per horse-power per hour for ten hours a day, in an engine of 100 horse-power, assuming that the boiler evaporates 7 pounds of water per pound of coal, would make a saving of 1000 pounds of water per day, which would require the consumption of 143 pounds of coal — $22\frac{1}{2}$ tons a year — the cost of which would be, at the ordinary price of coal, over $125.

The methods most in vogue for the consumption of all kinds of fuel are those which gradually developed themselves, as necessity dictated, to the untutored intellect of uncultivated men, but which, however creditable to the men that devised them, inasmuch as they availed themselves of all the sources of information within their reach, are nevertheless a reproach to the more advanced knowledge of physical and mechanical science enjoyed by the present generation.

Even with the best coal and most careful firing, a quantity of the coal falls through the fire-bars either as unburnt coal or ashes. Another portion goes up the chimney, unconsumed, in the form of smoke and soot; and a further quantity, half consumed, in the form of carbonic oxide. The loss from these causes may amount to from two to twenty per cent. It all

arises from wrongly constructed furnaces and bad firing, and can nearly all be avoided. Most coal contains a greater or less quantity of moisture, and the evaporation of this moisture causes the first loss of heat. Radiation from the furnace causes a further loss. But the great causes of loss are the admission into the furnace of a large quantity of useless air and inert gases, and the escape of these, with the actual products of combustion, up the chimney at a very much higher temperature than that at which they entered the furnace.

Air is composed of about one-third oxygen and two-thirds *nitrogen*. The *oxygen* only is required to effect the combustion of the fuel, and the useless *nitrogen* merely abstracts heat from the combustibles and lowers the temperature of the furnace. About 12 pounds of air contain sufficient oxygen to effect the combustion of 1 pound of coal; but, owing to the difficulty of bringing the carbon into contact with the *oxygen*, the quantity actually required to pass through the furnace is from 18 to 24 pounds of air per pound of coal burnt. The surplus air passes out unburnt, and its presence in the furnace lowers the temperature there and abstracts a portion of the heat generated. As the whole of the air enters the furnace at about 60° Fah., and the unconsumed air and products of combustion leave the flues at from 400° Fah. to 800° Fah., the total loss from these causes is from 20 to 50 per cent. Each pound of

good coal burnt is theoretically capable of evaporating about 14 pounds of water. In practice, under the most favorable circumstances, it evaporates but from 7 to 9, and in ordinary practice from 4 to 6.

There are difficulties in the way of abstracting all the heat from the furnace gases. First, because, with natural or chimney draught, the gases require to pass into the chimney at not less than 500° Fah., in order to maintain the draught; and, secondly, because the transmission of heat from the gases to the water, when the difference of their temperatures is small, is so slow that an enormous extension of the surface in contact with them becomes necessary in order to effect it. But by having energetic combustion and a high temperature in the furnace, the quantity of air actually required may be much reduced. By suitable arrangements for admitting air and feeding coal into the furnace, the proportions of each may be suitably adjusted to each other; and by a liberal allowance of properly disposed heating-surface, the temperature of the gases may be reduced to that simply necessary to produce a natural draught, or to about 400° Fah. or less, in a furnace where the draught is obtained from a steam-jet or fan.

Before starting a fresh fire, any dust, ashes, or cinders that may have remained in the furnace after the fire was drawn, should be removed and the surface of the bars made perfectly clean and level; then a thin layer of fresh coal should be scattered over

the grates for the purpose of protecting them from the extreme heat of the fresh fire, as the coal so scattered will absorb the heat that would otherwise be transmitted to the grates, and cause them to spring or warp. The fresh fuel will also cause the fire to burn more moderately, which is an object of great importance when boilers are cold. Most of the kindling, whether light wood, shavings, oily-waste, or paper, should be placed in the front end of the grates, near the furnace door, and then covered with a uniform layer of wood. This is a necessary precaution, as, when the fuel fails to ignite at the front at first, it generally takes a long time before the fire burns through.

When a boiler is of sufficient capacity to generate the necessary amount of steam, without urging the fires, it will be found most advantageous to carry a thick bed of coal on grates, as, when the coal can be burned in large quantities and with a moderate draught, the heat is more generally utilized than if the coal is burned in small quantities and with a sharp draught. For stationary boilers, the fuel should not be less than from 3 to 4 inches thick on the grate; for marine or locomotive boilers, if anthracite coal be used, from 5 to 6; if bituminous, from 6 to 8 inches. Of course, the thickness of the fire must be governed by the character of the fuel and quantity of steam required.

When the coal is in large lumps, so that the

space between them is considerable, the depth may be greater than where the coal is small and lies compactly; and where the draught is very strong, so that the air passes with great velocity over and through the fuel, there is not time for the carbonic acid to combine with and carry off the products of combustion, and consequently a bed of greater depth may with propriety be used. When very large coal is used, it will be found of advantage to mix it with some small coal, particularly when the draught is strong, as such an arrangement forms a resisting barrier to the currents of cold air that would otherwise pass through the interstices between the lumps, and render the combustion more perfect.

When an increased quantity of steam is wanted, the average thickness or quantity of fuel on the grate must not be increased, but rather diminished, and supplied in smaller quantities and more frequently. As soon, however, as the supply of steam exceeds the demand, the coal may again be supplied in larger quantities at a time. When it becomes necessary to replenish the fire, it should be done as quickly as possible, as, when the damper and the fire-door are both open at the same time, the current of cold air passing through the furnace above the fuel not only reduces the temperature in the furnace, but has a tendency to injure the boiler.

There should in all cases be ample fire in the furnace, an extra quantity of water in the boiler, and

a full head of steam, before any attempt is made to clean the fire. Then the damper should be opened to its full extent, in order that the heated gases and dust may pass into the flue; and if there be more than one fire, one only should be cleaned at a time, and allowed to become thoroughly kindled before the next one is cleaned. The fire should never be allowed to become low for the purpose of making it more easy to clean, as, in consequence of the small quantity of fire in the furnace after cleaning, the combustion is checked, the temperature of the furnace lowered, and consequently a serious loss of fuel incurred.

It is always best to have a good fire in the furnace before commencing to clean; then close the damper and open the furnace door for a few minutes, in order to take the white glare off the fire before commencing to clean it. The damper should then be reopened to its full extent and all the live fire pushed back to the bridge, without disturbing any of the ashes or cinders. The latter should then be drawn out, and the fire that was pushed back drawn forward, and the ashes and cinders that remain near the bridge removed. The fire should then be distributed evenly over the grate, all the cinders and clinkers that remain picked out, and the fire covered with a thin layer of fresh coal, care being taken to waste none of the combustible fuel.

The fire should never be disturbed so long as any

light shines through the grate into the ash-pit, unless the boiler fails to furnish the necessary amount of steam. Even then it is better, if anthracite coal be the fuel, to shed out the ashes from the bottom through the grate with a thin, hooked poker. But, if bituminous coal be used, it requires frequent breaking up, in order to allow the air to intensify the combustion. When broken up, it should always be pushed back toward the bridge, fresh fuel supplied in the front, and allowed to coke. The smaller the quantity supplied at a time, and the more attention paid to its distribution and regulation, the more perfect will be the combustion, and the more intense the heat.

If, from neglect or any other cause, the fire should become low or the grate partly stripped, it should not be poked or disturbed, as that would have a tendency to put it entirely out; but wood, shavings, sawdust, greasy-waste, or some other combustible substance, should be thrown on the bare places, and after being covered with a thin layer of coal, the damper opened to its full extent. The regulation of the draught should receive particular attention, as air costs nothing, while fuel is quite expensive. Therefore none of the latter should be allowed to pass out of the furnace without being fully utilized. The ash-pit and front of the furnace should at all times be kept free from dirt, ashes, and cinders, as such accumulations have not only the effect of diminishing the cubic contents of the space under the fur-

nace, but also of obstructing the free current of air through the grate-bars, so essential to the perfect combustion of the fuel.

It is a well-known fact, that much of the waste attributed to the steam-engine occurs in the furnace, and may be summed up as follows: *Waste* of unburnt fuel in the solid state; *waste* of unburnt fuel in the gaseous or smoky state; *waste* by external radiation and conduction; *waste* by the excess of heat which escapes by the chimney over that required for the draught. These sources of waste give rise to excessive losses, which perfect arrangement and good management may tend to avoid; and if the arrangement and proportion of the boiler are good, the losses which occur in the consumption of fuel may be attributed, in a great measure, to the ignorance, inattention, or carelessness of the fireman.

Clean grate-bars, with an even distribution of the fuel in the furnace, the exercise of judgment in the quantity of air admitted, and the regulation of the draught, are the main points to be attended to; and although they require the exercise of skill and intelligence, they cannot be said to involve an unreasonable amount of either labor or vigilance.

When it becomes necessary to supply fuel to a boiler furnace, or to clean, slice, or poke the fire, it should be done with decision, quickness, and energy, as, when the furnace door and damper are open at the same time, the cold currents of air passing in

above the fuel have a tendency not only to lower the temperature of the furnace, but to impinge on the parts of the boiler most exposed to the fire, which induce contraction, leakage, and permanent injury.

DAMPERS.

In the foregoing chapters such articles and attachments as have for their object the control and regulation of the water, the designation of the steam pressure, and the cleaning of boilers, have been considered. It may not now be out of place to call attention to appliances for regulating the draught in furnaces, flues, and chimneys, which, as now employed, are few and simple, consisting either of a circular plate, which swings in a round flue, or a square plate sliding in an iron frame. The importance of efficient dampers has never received due consideration either from engineers or steam-users, when we consider how largely they contribute to the economy of fuel, by retarding the combustion which would generate steam in excess of that needed, and also by preventing the cold air from escaping into the flues when the boiler is not in use, thereby lowering the temperature of the boiler and its surroundings, and involving the expenditure of an extra quantity of fuel when steam is raised. The damper illustrated on page 339 is one of the most simple and efficient devices ever invented for the regulation of draughts in the furnaces of steam-boilers.

NO one who desires to be proficient in his art will rest satisfied with a knowledge of the mere routine duties required. It is not enough to know that certain results are produced from certain causes; this we may learn from mere experience. But, in order to become really intelligent, we must go further, and learn why the causes produce the results, so that, in an emergency, other means may be substituted to accomplish the desired ends.

STEAM-BOILER INSPECTION.

It is asserted, on reliable authority, that the proportion of boiler explosions and ruptures, as compared with the number of boilers in use, exceeds the number of fires in buildings as compared with the number of buildings in the country. It is estimated that there are upwards of 100,000 steam-boilers in use in this country; the number of explosions annually is from 125 to 150, but when to these are added the ruptures, collapsed flues, ripped seams, etc., the number of disasters is increased to 900 or 1000, making one per cent. of the whole number in the country damaged more or less annually.

The use of steam-power is increasing the world over, and it will continue to increase until some new motor, more effective and less expensive, is discovered. Therefore, intelligent and thorough boiler inspection is one of the imperative necessities of the age. The manufacturer or steam-user, from a press of business or a want of that practical knowledge which is only attained in any pursuit by close study and observation, is unable to attend or give directions in all the details involved in the care and management of his steam-boilers. For a very small consideration, he can avail himself of the advantages to be derived from the inspection and insurance of steam-boilers, by placing his boilers under the care of responsible and reliable parties, who will do

everything that can be done to insure safety. The experience of the past in the care and management of steam-boilers has shown the necessity of such a system, as it not only gives additional security from the effects of boiler explosions, but also refutes the false and absurd theories which have tended to divert the attention of engineers and owners of steam-boilers from that watchfulness so essential to their care and management, by inducing the belief that no amount of care on their part will avail against certain mysterious agents at work within their boilers.

Another advantage of intelligent and practical steam-boiler inspection is, that it gives the engineer an opportunity to inform himself on many points of vital importance, by conversing with one who, from making a special business of boiler-inspections, has become thoroughly versed in all matters pertaining to boilers and their attachments; consequently, every engineer and fireman should afford boiler-inspectors every facility to make a thorough examination of the boilers in their charge. They should give them all the information and facts relating to the same, as it may not only be the means of saving their own lives, but of many others, as well as much valuable property. It is the duty of all engineers, steam-users, and those who take an interest in the lives and property of their fellow-man, to encourage careful, thorough, and intelligent steam-boiler inspection,

which, to be efficient, must have a pecuniary interest involved in its operations, as those who sustain no loss, either of time, means, or salary, are apt to become derelict of duty.

RULES FOR FINDING THE QUANTITY OF WATER WHICH BOILERS AND OTHER CYLINDRICAL VESSELS ARE CAPABLE OF CONTAINING.

Rule for Cylinder Boilers.—Multiply the area of the head in inches by the length in inches, and divide the product by 1728; the quotient will be the number of cubic feet of water the boiler will contain.

EXAMPLE.

Diameter of head, 36 inches.
Area " " 1017.87 "
Length of boiler, 20 feet, or 240 inches.

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        1017.87
            240
        -------
        4071480
       203574
       -------
1728)244288.80
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        141.37 cubic feet.
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Rule for Flue Boilers.—Multiply the area of head in inches by the length of the shell in inches; multiply the combined area of the flues in inches by their length in inches; subtract this product from the first, and divide the remainder by 1728; the

quotient will be the number of cubic feet of water which the boiler will contain.

Rule.—*To find the Requisite Quantity of Water for a Steam-boiler.*—Add 15 to the pressure of steam per square inch; divide the sum by 18; multiply the quotient by .24; the product will be the quantity in U. S. gallons per minute for each horse-power.

Rule.—*To find the Required Height of a Column of Water to supply a Steam-boiler against any given Pressure of Steam.*— Multiply the boiler pressure in pounds per square inch by 2.5; the product will be the required height in feet above the surface of the water in the boiler.

Another Rule.—*To find the Requisite Quantity of Water for a Steam-boiler.*—When the number of pounds of coal consumed per hour can be ascertained, divide it by 7.5, and the quotient will be the required quantity of water in cubic feet per hour.

EFFECTS OF DIFFERENT KINDS OF FUEL ON STEAM-BOILERS.

Anthracite coal is undoubtedly the most trying fuel on the parts of steam-boilers exposed to its direct action, but nevertheless it is less destructive to the whole structure than either coke, wood, or bituminous coal. This arises from the fact that it can be consumed in more uniform quantities, and offers better facilities for the regulation of the air

than any other kind of fuel that might be used, as the grate-surface can be easily covered with a uniform stratum necessitating the passage of the air through it, which limits the quantity according to the thickness of the fuel on the grates, rendering the combustion more moderate and uniform. While, on the other hand, the combustion of coke, bituminous coal, and wood, is, at times, of the most fierce and energetic character; and, in consequence of the impossibility of maintaining a uniform fire with these three last-named kinds of fuel, large quantities of air are admitted, which has a very deteriorating effect on all parts of the boiler, as they are continually exposed to the evils induced by extreme expansion and contraction.

BOILER MATERIALS.

Boiler-making now holds an important place among the mechanical arts. Its progress has been aided chiefly by the enormous growth of the steam-engine, as the prime mover, and also by the increased facilities afforded for procuring suitable materials and by the improvements made in working them. In the early days of the steam-engine, boilers of copper and cast-iron were used for generating steam, but they were seldom subjected to a higher pressure than that of the atmosphere; but when pressures of 3 to 4, or even 7, atmospheres came into use cast-iron was

found to be unreliable and treacherous, for which reason it was discarded in favor of *wrought-iron*, which was not employed at first, in consequence of the difficulty found in working it and in making steam-tight joints. It has, however, of late years become the material employed to the almost entire exclusion of all others. In fact, it has been more extensively used in the construction of steam-boilers, for the past thirty years, than any other material, doubtless on account of its great tensile strength, together with its ductility, power of bearing sudden and trying strains, and general trustworthy nature; its moderate facilities of working, the ease with which it can be welded, riveted, patched, or mended; its moderate first cost, etc.

The first quality to be sought for in boiler material is strength. This does not necessarily imply the mere power to resist being torn asunder by a dead-weight, as in a testing-machine, but the quality to withstand, without injury, the varying shocks and strains to which boilers are exposed. An inferior quality of plates cannot be relied upon to bear the ordeal of repeated heating and cooling, as they invariably warp and twist, showing defects of manufacture; more especially in the process of cold-bending, when minute fractures often occur on the outer surface of the plates of stubborn or inferior qualities of iron.

The defect most commonly revealed in working

boiler-plates is lamination. This defect arises from the imperfect welding of the several layers which make up the thickness of the plate, and is usually caused by interposed sand or cinder, which has not been expelled in hammering or rolling during the process of manufacture. This is more frequent in thick than in thin plates, and is sometimes very difficult to detect in cold plate, although often discernible in the hot. It also often happens that plates, which are passed as quite sound, on careful external examination, are found to be severely laminated when subjected to heating and hammering, and prove totally unfit for use.

Blisters are of a similar nature, and arise from the same cause as lamination. Sometimes they appear as mere surface defects, and are of no consequence; but their appearance may be an indication of the want of care or skill in the making of the plate, and should always excite suspicion. It frequently happens that these defects pass undetected after the closest scrutiny and test by hammering, but disclose themselves soon after the boiler is set to work, especially if the plates be exposed to sudden variations of temperature. In the plates over the fire-grate of an externally-fired boiler such a blister may prove a very serious defect, and often necessitates the cutting out and replacement of the sheet. Inferior brands of iron will rapidly show unmistakable signs of weakness, when placed under the

trying ordeal of bearing the alternate impingement of a fierce flame and currents of cold air. The rapid variations of temperature caused by the sudden and frequent openings of the furnace-door and leakage of cold air through the grate-bars will soon tell on any kind of iron, but more quickly on that of an inferior brand.

Characteristics of Boiler Iron when Broken. — On breaking a plate or bar of wrought-iron the fracture presents an appearance by which the quality of the iron may, in some measure, be determined. The fracture is designated on the one hand as fibrous, tough, silky, close-grained, etc., or, on the other hand, crystalline, coarse, open-grained, brittle, and cold-shut. When broken suddenly the best qualities of plate- and bar-iron exhibit a fine, close-grained, uniformly crystalline fracture, even silky, of a light, silvery color; the appearance in the harder descriptions approaching to that of steel. The appearance of indifferently refined and inferior qualities is coarser, usually of a darker color, more or less uneven or open, exhibiting large facets, and approaching some descriptions of cast-iron. When broken gradually, good iron presents a well-drawn out close fibre, of light greenish hue, whilst inferior qualities give a shorter, more open and darker fibre.

When good ductile iron is gradually torn asunder it draws out or stretches to a considerable extent, causing a diminution of sectional area at the frac-

tured part, which should always be compared with the original sectional area of the specimen in judging of the quality. An inferior bar or plate may bear as great a tensile strain as a similar specimen of superior quality; but, on comparing their fractured areas, it will generally appear that the latter has been drawn out considerably, whilst the inferior specimen, having stretched but little, has not sensibly diminished at the fracture. This is owing to the fact that good ductile iron is so much more trustworthy than badly refined, when sudden strains occur. The one will stretch, while the other will snap. It is also a well-known fact that wrought-iron changes from fibrous to crystalline after enduring long-continued cold hammering, vibration, tension, jarring, and other strains, after long exposure to the influence of heat, or alternate expansion and contraction, whenever it has been used for the plates of a boiler-furnace. Even the very best plates, after from ten to twenty years' use in a boiler, have frequently been found to break without stretching, at the same time displaying a crystalline fracture.

It has been said that this shows that a change has taken place in the nature of the material, and that, from being fibrous and tough, it has, by some unexplained cause, become crystallized and brittle, or that it has lost its nature in consequence of the treatment it has undergone, whatever that may have been.

There is no doubt that the strains and other causes above mentioned have a tendency to make good iron become brittle and liable to snap suddenly under the same treatment that would originally have torn it, gradually, and to this extent a change is produced in its nature. This snapping, and not the fatigue of the metal, is however the direct cause of the crystalline fracture, which is but a necessary consequence of the suddenness of the breaking, and not a property of the iron itself. To say it snaps readily because it has become crystalline is to confound the cause with the effect. It is erroneous to say the fibrous nature has passed out of the iron, for its ductility can, to some extent at least, be restored, in most cases, by simply heating to a bright red, and slowly cooling the iron, or, failing that, by hammering or rolling it while hot. By heating to redness and suddenly cooling a piece of wrought-iron, it will become liable to snap, producing the same effect as cold hammering. The explanation of this is not clear, and it may be owing to the loosening of the crystals, into which the composition of the material ultimately resolves itself. To this cause may also be attributed the same tendency to snap after long-continued jarring, or alternate expansion and contraction.

It may be asserted, without fear of contradiction, that all boiler-plate worthy of the name is fibrous; whether its hardness makes it liable to snap, and therefore appear crystalline, depends on its original

character and the treatment it has undergone. No fine iron can, however, by any treatment, except burning, be made to appear coarse, and the fibres of the poorer descriptions of iron cannot, without refining, be made to appear fine and close-grained. It is from a want of knowledge of the above facts that false opinions are so often expressed respecting the qualities of boiler-plates.

It is no unusual thing to find intelligent mechanics and boiler-makers expressing their opinions at coroners' inquests on the quality of the iron in exploded boilers, without anything to base their opinions on except the load per square inch required to tear the plates asunder; they seem to forget that if the boiler be an old one, that the age, the position in the boiler in which the rent has taken place, the amount of strain to which it has been exposed, and all the circumstances connected with the occurrence, should be known in order to decide understandingly as to the quality of the iron. It has been shown in numerous instances that good ductile iron can be made to appear crystalline when pulled asunder in the testing-machine, by confining the minimum sectional area where fracture will occur to one point or to a very short length.

The general conclusions, with regard to boiler material, which may be regarded as established from experiments, observation, and practice, thus far seem to be — 1st. That the laws of resistance of the parts

of boilers to the internal pressure are sufficiently well established. 2d. It is of the utmost importance that the materials employed should be of the best quality as regards strength and durability; and as there are but few manufacturers of boiler-plates, the inspection of materials, especially boiler-plates, should be made by competent persons appointed for that purpose, at the place of manufacture, which inspection should extend to the qualities of ores and the process of manufacture; the required stamps, brands, or certificates being put on or authorized by the inspectors in person. There is much greater certainty of securing the best materials by an inspection of the process of working and the raw materials employed, than by an inspection of plates after they have been sent to market, when, judging from all external appearances, good and bad plates are not easily distinguished.

Practical limits to the thickness of boiler-plates. The proper strength of boilers, in order to enable them to withstand with safety the required pressure of the steam, is a matter of much importance as regards both life and property; and the responsibility of the proprietors and constructors of boilers is of so grave a character as to justify the devotion of a much larger space to this subject than is convenient in this work. The principles on which the strength of all boilers, of whatever material, depend, may be expressed in a very few words — the strength being directly as the thickness of the metal, and inversely as the diameter of the boiler.

So long as the quality of boiler iron remains as it is at present, the thickness of the plate may be practically determined within exceedingly narrow limits, as a good boiler must be constructed of plate ranging in thickness from not less than one-fourth to not greater than one-half an inch, as anything less than the former cannot be properly calked, and any thickness greater than the latter is difficult to rivet without the aid of machinery. A thickness of three-eighths seems to have become the standard thickness for all diameters of boilers intended to sustain a high pressure; this, perhaps, arises from the fact that boiler-makers seem to be better acquainted with the practical limit to the strength of that thickness, because it has, of late years, been used more than any other; nevertheless, for steel, of some of the higher grades of American plate, a less thickness will suffice for the same pressure.

STEEL.

As steel is likely to be universally adopted as a material for boiler-shells, it is unnecessary to look forward to any further progress in the direction of obtaining a stronger material. Therefore, any effort to increase the strength of boilers should be directed to the selection of the best material, and to the most practical methods of disposing of it.

Steel seems to meet the demand for the new mate-

rial, and has been able, under very varying circumstances, within the past seven or eight years, to establish its superiority over iron or copper. In comparing the properties of steel and iron plates, there can be no doubt that the processes employed in the production of cast-steel are immensely superior to those employed in the manufacture of wrought-iron, for insuring a uniform texture in the material. Cast-steel plates, made from a fluid mass run into a single ingot, and when well worked under the hammer, are likely to be perfectly homogeneous and free from the imperfect welds and internal defects caused by the presence of cinder and slag, either of which is frequently found even in the best-puddled iron, which, being built up of numerous small pieces, all more or less properly welded together, is entirely dependent upon the skill and care exercised in its production for its homogeneity and freedom from lamination, blisters, and other internal defects.

It was probably the high degree of tenacity and ductility, exhibited by tool- and spring-steel, that first drew attention to the advantages offered by this material for the construction of steam-boilers. Its high price, however, long stood in the way of its being largely adopted; and this obstacle was only removed by the introduction of new methods of manufacture, which can as yet be termed improvements only with respect to their commercial success,

and not as affecting the quality of the material. There can be little doubt that the adoption of steel for boiler-plates has been retarded by the want of knowledge of its properties, and the consequent difficulty sometimes met with in working it. The result of this is a disposition on the part of the great majority of boiler-makers to avoid using it as much as possible.

It has been found by experiment with different qualities of steel-plates that toughness is incompatible with great tensile strength, and these two qualities may be considered as being in the inverse ratio to each other. If it becomes necessary to have steel with a tensile strength of from 90,000 to 100,000 pounds, it will be found to be hard and brittle, and, therefore, not adapted for boiler-plates. In order to insure freedom from brittleness, a tensile strength of from 60,000 to 80,000 pounds is the maximum that can be allowed. The high degree of tensile strength exhibited by steel-plates allows the use, with safety, of this material thinner than either iron or copper, thus reducing the weight, and rendering the difference in first cost of material an item of less magnitude than is usually supposed. Besides the weight saved by using steel — often a most important consideration — it may be urged that the thinner plates will conduct the heat more rapidly, and give a correspondingly superior evaporative efficiency. This superiority is not, strictly speaking, in propor-

tion to the reduction of thickness, since the relative conducting powers of steel and iron are about 244 and 218. Then the density and perfect homogeneity of steel render it nearly impervious to the action of sulphur and other foreign ingredients existing in coal and water, which have proved so destructive to iron and copper.

Effect of Punching on Steel-plates.— One of the principal results obtained, both from experiments and experience of the material in actual riveted work, is that steel-plates of average suitable quality are more injured than wrought-iron plates by punching. It is chiefly ship-builders to whom boiler-makers are indebted for exact experimental knowledge on the behavior of steel-plates in the process of punching.

STRENGTH OF IRON BOILER-PLATE.

Although there is great variation in the tensile strength of rolled iron boiler-plate, since that of good plate will average about 50,000 pounds per square inch, if the strain is applied in the direction of the "grain" or the fibres of the iron (or the direction in which it has been rolled), and about ten per cent. less if the strain is applied crosswise of the grain, it has, however, been found by experiment that, when a tensile strain is applied to a bar of iron or other material, it is stretched a certain amount in

proportion to the length of the bar and to the degree of strain to which it is subjected. It is found that if this strain does not exceed about one-fifth of that which would break the bar, it will recover its original length, or will contract after being stretched, when the strain is removed.

The greatest strain which any material will bear, without being permanently stretched, is called its limit of elasticity; and so long as this is not exceeded, no appreciable permanent elongation or "set" will be given to iron by any number of applications of such strains or loads. If, however, the limit of elasticity be exceeded, the metal will be permanently elongated, and this elongation will be increased by repeated applications of the strain, until finally the bar will break.

At the same time, the character of the metal will be altered by the repeated application of strains greater than its elastic limit, and it will become brittle and less able to resist a sudden strain, and will ultimately break short off. It is, therefore, unsafe to subject iron, or, in fact, any other material, to strains greater than its elastic limit. This limit for iron boiler-plates may be taken at about one-fifth its breaking, or, as it is called, ultimate strength. It should be remembered, however, in this connection, that it often happens that the steam pressure is not the greatest force the boiler must withstand, as sudden or unequal expansion and contraction are

probably more destructive, to locomotive boilers especially, than the pressure of the steam.

The manufacture of boiler-plates is carried on very extensively in the United States, especially in Pennsylvania. American iron is naturally stronger and tougher than the English, bearing an average tensile strain of from 60,000 to 70,000 pounds per square inch, while the best Yorkshire iron bears only about 56,000 pounds to a square inch, and the Staffordshire about 44,800 pounds. The mean tensile strength of American *cast*-iron has been determined with considerable care by means of experiments conducted for the United States Government. Major Wade, of the U. S. Ordnance Corps, found that the mean tensile strength of American cast-iron was 31,829 pounds per square inch of section; while the tensile strength of the English *cast*-iron, as determined by Mr. Hodgkinson for the railway companies, is very much inferior to this — being but 19,484 pounds to the square inch.

DEFINITIONS AS APPLIED TO BOILERS AND BOILER MATERIALS.

Cohesion is that quality of the particles of a body which causes them to adhere to each other, and to resist being torn apart.

Curvilinear Seams.— The curvilinear seams of a boiler are those around the circumference.

Elasticity is that quality which enables a body to return to its original form after having been distorted, or stretched, by some external force.

Internal Radius.— The internal radius is $\frac{1}{2}$ of the diameter less the thickness of the iron. To find the internal radius of a boiler, take $\frac{1}{2}$ of the external diameter and subtract the thickness of the iron.

Limit of Elasticity.— The extent to which any material may be stretched without receiving a permanent "set."

Longitudinal Seams.— The seams which are parallel to the length of a boiler are called the longitudinal seams.

Strength is the resistance which a body opposes to a disintegration or separation of its parts.

Tensile strength is the absolute resistance which a body makes to being torn apart by two forces acting in opposite directions.

Crushing strength is the resistance which a body opposes to being battered or flattened down by any weight placed upon it.

Transverse strength is the resistance to bending, or flexure, as it is called.

Torsional strength is the resistance which a body offers to any external force which attempts to twist it round.

Detrusive strength is the resistance which a body offers to being clipped or shorn into two parts by such instruments as shears or scissors.

Resilience, or toughness, is another form of the quality of strength; it indicates that a body will manifest a certain degree of flexibility before it can be broken; hence, that body which bends or yields most at the time of fracture is the toughest.

Working Strength. — The term "working strength" implies a certain reduction made in the estimate of the strength of materials, so that, when the instrument or machine is put to use, it may be capable of resisting a greater strain than it is expected on the average to sustain.

Safe Working Pressure, or Safe Load.—The safe working pressure of steam-boilers is generally taken as $\frac{1}{5}$ of the bursting pressure, whatever that may be.

Strain in the direction of the grain, means strain in the direction in which the iron has been rolled; and in the process of manufacturing boiler-plates, the direction in which the fibres of the iron are stretched as it passes between the rolls.

Stress.—By the term "stress" is meant the force which acts directly upon the particles of any material to separate them.

There is another property of boiler materials which has been named "fatigue of metals." It refers to that ultimate tendency to wear out, from which material and inanimate substances seem no more exempt than living creatures. It may be explained, perhaps, by the "stretch," and consequent weakening, which experiments establish as a quality of the

toughest iron. The following are the results of a series of experiments made by Captain Rodman, at the United States Arsenal at Watertown, upon the iron manufactured by a well-known firm in Baltimore. A square inch of the best flange iron was subjected to the various strains mentioned, with such results, as to temporary and permanent stretch, as are shown in the annexed columns:—

Amount of Strain.	Temp'y Stretch. $\frac{100}{1000}$ of an inch.	Permanent Stretch. $\frac{100}{1000}$ of an inch.
5,000 lbs.....	20	0
10,000 "	41	1
15,000 "	57	1
20,000 "	76	3
25,000 "	100	7
30,000 "	537	408
35,000 "	1833	1661
40,000 "	4000	
45,000 " broke.....		

It will be seen from the above table that the first essay, by means of a strain of 5,000 lbs., produced no permanent stretch in the bar; and that 10,000 lbs. and 15,000 lbs., respectively, only produced a permanent stretch of $\frac{100}{1000}$ of an inch, or about $\frac{1}{10}$ of the temporary stretch. But in the next two strains of 20,000 and 25,000 lbs., the iron begins to show a great acceleration of the weakening process or increase of fatigue, for now the permanent strain has sprung up to $\frac{1}{15}$ of the entire stretch. In the two

next items this acceleration is astounding, the permanent stretch being $\frac{3}{4}$ of the whole upon 30,000 lbs., and $\frac{9}{10}$ of the permanent stretch of 35,000 lbs.

PUNCHED AND DRILLED HOLES FOR BOILER SEAMS.

Punching rivet holes, according to Fairbairn's experiments, is in itself a cause of weakness. Not only is the section of the plate in the line of the strain reduced by the area of the holes, but the plate between the holes is not so strong per square inch as the solid plate. The excessive strain of the punch appears to disturb the molecular arrangement of the metal, and to start fractures which, in case of stay-bolts, often radiate in every direction, allowing corrosion to take place, and ultimately causing the bolts to pull out of the plate.

In eight experiments by Fairbairn, the highest strength of plate experimented upon was 61,579 lbs., and the lowest 43,805 lbs., per square inch; but with the same plates, after punching, the strength per square inch varied between 45,743 lbs. and 36,606 lbs. The average of the two experiments, therefore, showed a loss of 10,896 lbs. per square inch, due to the jar and strain of punching, in addition to the loss of section through the holes.

In the process of punching, from a want of accuracy in laying off the holes, through ignorance

or neglect of workmen, the holes do not come opposite, sometimes half, their diameter; they are then drifted until the sheet is fractured, and the material partly destroyed.* This habit cannot be too much reprehended, and the use of drift-pins, although considered indispensable by many good boiler-makers, is productive of great evils. As a result, when the rivets are driven, it is almost impossible to make them fill the holes, and consequently an undue strain will come upon some of the rivets, while upon others there will be very little. In that case, there is danger of shearing off the rivet upon which the extra strain comes, inducing a strain upon the adjoining holes, and thus starting a rupture, which will ultimately result in the destruction of the boiler.

The usual arguments in favor of punching are a saving of from one-third to one-sixth of time and labor, as compared with drilling — a most conclusive argument with the manufacturer; but it is argued, on the other hand, that the positions of the holes marked off from the overlapping plate can be preserved more faithfully with the drill than with the punch. This, doubtless, is a very strong argument, as it is well known that half-blind holes are the bane of boiler-making. But it must be understood that the quality of the plate has an important influence on its manner of bearing the severe treatment it undergoes at the hands of the punching-machine.

* See page 231.

Inferior and badly refined plates, being brittle, suffer to a much greater extent than those of better and more ductile quality. In fact, punching a hole at the usual distance from the edge (one diameter clear) in an inferior plate will often produce fracture.

The violence done to the plate may be seen more clearly by considering the force requisite to punch it. It has been found by experiment that the resistance of a wrought-iron plate to punching is about the same as its resistance to tearing by a tensile strain. Recent experiments authorized by the United States Government, at the Washington Navy-Yard, establish the fact that drilled holes for boiler-seams are nineteen per cent. stronger than holes that are punched. From this it is obvious that the rivet-holes for all longitudinal seams of steam-boilers should be drilled. The curvilinear seams, being subjected to only about half the strain of the longitudinal, might be punched. It is also worthy of note that, while the punched plate is weaker than the drilled plate, the rivets in the punched holes do not shear so easily as those in the drilled holes. This is probably due to the edges of the drilled holes being sharper and more compact, and consequently more capable of shearing than the edges left by a punch.

Experiments on drilled and punched holes have shown conclusively that rivets in drilled holes, subject to shearing strain, were about four per cent. weaker than rivets in punched holes, under similar

strain, and that the sharp edges of the drilled holes have a greater tendency to nip off the rivets than the rounded edges of the punched holes. In comparing the strength of punched and drilled work, it was found, *First*, that drilled plates are 19 per cent. stronger than punched; *second*, that rivets are 4 per cent. stronger in punched holes than in drilled; *third*, that there is a difference of 15 per cent. in favor of drilled work.

The following table shows the result of experiments on strips of boiler-iron cut from the same plate, two being punched and two drilled, with one inch holes, having a sectional area at the reduced part of $1\frac{1}{2}$ square inches.

Breaking Weight in Tons.			Difference in tons.	Difference per cent. in favor of drilled.
Experiment.	Drilled bar.	Punched bar.		
1st.	$30\frac{1}{2}$	26	$4\frac{1}{2}$	17
2d.	$31\frac{1}{2}$	26	$5\frac{1}{2}$	21
Mean.	31	26	5	19

The following are the results of experiments to test the difference in value between rivets in punched holes and similar rivets in drilled holes:—

$\frac{5}{8}$ inch Rivets in Drilled Holes.

First, single shear = 26 tons per square inch.
double shear = 39.2 tons.

Second, single shear = 26.4 tons per square inch.
double shear, experiment failed.

$\frac{5}{8}$ *inch Rivets in Punched Holes.*

First, single shear = 27.2 tons per square inch.
double shear = 45.6 tons.
Second, single shear = 26 tons per square inch.
double shear, experiment failed.

It is generally assumed that plates of fair quality, having a tenacity of 42,000 pounds per square inch, cannot be relied upon to bear more than 32,000 to 34,000 pounds per square inch of section left between holes in ordinary steam-tight riveted joints, which would be equivalent to about 24 and 20 per cent. loss of strength. This is about a maximum loss for hard plates of average equality; but many soft plates do not suffer more than from 5 to 10 per cent. loss of strength; with the holes punched a whole diameter, clear of the edge, and at the second row of rivets, in double-riveting, do not suffer so much. The damage by punching diminishes as the distance of the hole from the edge increases; consequently, some boiler-makers, who prefer punching to drilling, have their plates cut about half an inch larger than their finished size, in order to keep the holes at a safe distance from the edge in punching; the surplus material being afterwards either chipped or planed off.

Welding the seams of boilers would be of immense advantage, since the welded joint is nearly twice as strong as the riveted joint; and since twice as much steam pressure is exerted on the longitudinal seams of the cylinder of a boiler as on its circular seams, the right proportion of strength would be preserved by welding the former and riveting the latter. The following advantages would be acquired by welding the seams of boilers:— 1st. It would cheapen the cost of construction, by saving much of the time occupied in riveting, and all that consumed in calking; 2d. The full strength of the plates being preserved, a thinner material would suffice; 3d. Much higher pressure could be carried without increasing the weight of the boiler; 4th. There would be no double thickness of plate to promote unequal expansion; 5th. Where the greatest strain would occur there would be no caps or joints, and consequently there would be no leakage.

TABLE

SHOWING THE STRENGTH OF WELDED BOILER-PLATES.

Width of Strip.	No. of Strips Tested.	Broke in Weld.	Broke in Solid.	Breaking Strength in Lbs. per Square Inch.		
				Least.	Greatest.	Mean.
1 in.	15	8	7	33,000	47,600	40,400
$1\frac{3}{8}$ "	4	2	2	39,200	44,400	42,000
$1\frac{1}{2}$ "	4	1	3	36,000	47,000	43,400
Total.	23	11	12	33,000	47,600	40,600

PATENT BOILERS.

The patent boilers not described and illustrated in this book, are the "Blanchard," "Lowe," "Howard," "Anderson," "Kelly," and "Lynde." They belong to the same class as the Moorhouse, Wiegand, Root, Allen, Harrison, etc., and differ from them only in the number of parts, as the principle attempted to be embodied in the design of sectional or patent boilers appears to be the same in all, although attempts have been frequently made to show that their design was based on some new principle in the generation of steam, which, on examination, would be found to be only a vagary of the designer or inventor, an alteration from some former design, or at best only a slight improvement on some generator already in use. This appears to be the age of boilers; inventors are continually taxing their brains to produce new steam-boilers, but so far most of their productions have either proved a failure or a very poor investment.

THE GALLOWAY BOILER.

The shells of the Galloway boilers (English) are made of Bessemer steel, generally $\frac{3}{8}$ of an inch thick. They have two furnaces to each boiler, composed of steel rings flanged and riveted together in such a manner that no seam or rivet comes in contact with the fire. The inside of the boiler is composed of an

oval flue, in which are placed a number of conical water-tubes, having the smaller end at the bottom and the larger at the top. These tubes serve as braces for the large flue, and on account of their shape afford easy access for the steam in its escape from the heating-surface to the steam-room.

Along the inside of the flue is a series of bafflers, which alter the direction of the heated gases from the furnaces to the chimney, and cause them to impinge on the water-tubes, thus increasing the heating surface. These boilers are claimed to be very efficient, and capable of evaporating 10½ pounds of water to one pound of coal, which, if true, has been frequently not only claimed, but accomplished in this country by boilers of more modest pretensions. The circumstances under which such wonderful evaporative capacity is developed, are rarely ever explained, and if investigated, it would probably be found that they were all very favorable to the boiler, possibly when the plates were new, clean, and free from incrustation, the fuel of the best quality, the combustion as perfect as possible, and the management of the most intelligent and experienced character.

The Galloway boiler owes its reputation in England to circumstances other than its efficiency, durability, and economy. It is expensive to build, and also to repair, as it requires special appliances for either purpose. Such boilers are not at all adapted to this country, nor is it possible ever to introduce them here to any extent.

THE engineer's duty, in the performance of the daily routine, involves the application of the laws of Nature in various ways. To build a fire intelligently is a chemical experiment, involving a knowledge of the principles of combustion. The production of steam, and its use as a motive power, depend upon other laws equally important and interesting.

STRENGTH OF RIVETED SEAMS.

The strength of a riveted seam depends very much upon the arrangement and proportion of the rivets; but, with the best design and construction, the seams are always weaker than the solid plate, as it is always necessary to cut away a part of the plate for the rivet holes, which weakens the holes in three ways: — 1st, by lessening the amount of material to resist the strains; 2d, by weakening that left between the holes; 3d, by disturbing the uniformity of the distribution of the strains. The *first* cause of weakness will appear obvious on the inspection of an ordinary boiler-seam, owing to the fact that forty-four per cent. of the original strength of the material had to be removed by the punch or drill to make way for the rivets. The *second* cause of the reduction of strength is owing to the injury sustained by the plates during the process of drilling and punching. The *third* cause of weakness is owing to the fact that if one or more holes are made in a plate of any material, and it is then subjected to a tensile strain, the strain, instead of being equally distributed through the section left between the holes, will be greatest in that part of the metal nearest it.

The strength of boiler seams may be calculated by taking the area, in square inches, of the metal between the holes, and *multiplying it by the ultimate strength of the metal, after the holes are punched.*

Single-riveted seams being equal to 56 *per cent. of the original strength, and double-riveted seams* 70 *per cent.*

COMPARATIVE STRENGTH OF SINGLE- AND DOUBLE-RIVETED SEAMS.

On comparing the strength of plates with riveted joints, it will be necessary to examine the sectional areas, taken in a line through the rivet-holes, with the section of the plates themselves. It is obvious that in perforating a line of holes along the edge of a plate, we must reduce its strength. It is also clear that the plate so perforated will be to the plate itself nearly as the areas of their respective sections, with a small deduction for the irregularities of the pressure of the rivets upon the plate; or, in other words, the joint will be reduced in strength somewhat more than in the ratio of its section through that line to the solid section of the plate. It is also evident that the rivets cannot add to the strength of the plates, their object being to keep the two surfaces of the lap in contact.

When this great deterioration of strength at the joint is taken into account, it cannot but be of the greatest importance that in structures subject to such violent strains as boilers, the strongest method of riveting should be adopted. To ascertain this, a long series of experiments was undertaken by Mr. Fairbairn. There are two kinds of lap-joints, single-

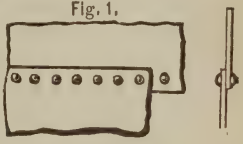
and double-riveted, as shown in Figs. 1 and 2 on opposite page. In the early days of steam-boiler construction, the former were almost universally employed; but the greater strength of the latter has since led to their general adoption for all boilers intended to sustain a high steam pressure. A riveted joint generally gives way either by shearing off the rivets in the middle of their length, or by tearing through one of the plates in the line of the rivets.

In a perfect joint, the rivets should be on the point of shearing just as the plates were about to tear; but, in practice, the rivets are usually made slightly too strong. Hence, it is an established rule to employ a certain number of rivets per linear foot, which, for ordinary diameters and average thickness of plate, are about six per foot or two inches from centre to centre; for larger diameters and heavier iron the distance between the centres is generally increased to, say two and one-eighth or two and one-fourth inches; but in such cases it is also necessary to increase the diameter of the rivet, for while five-eighth, or even half-inch, rivets will answer for small diameters and light plate, with large diameters and heavy plate experience has shown it to be necessary to use three-fourth to seven-eighth rivets.

If these are placed in a single row, the rivet-holes so nearly approach each other that the strength of the plates is much reduced; but if they are arranged in two lines, a greater number may be used, more

space left between the holes, and greater strength and stiffness imparted to the plates at the joint. Taking the value of the plate, before being punched, at 100, by punching the plate it loses 44 per cent. of its strength; and, as a result, single-riveted seams are equal to 56 per cent., and double-riveted seams to 70 per cent. of the original strength of the plate. It has been shown by very extensive experiments at the Brooklyn Navy-Yard, and also at the Stevens Institute of Technology, Hoboken, N. J., that double-riveted seams are from 16 to 20 per cent. stronger than single-riveted seams — the material and workmanship being the same in both cases.

Fig. 1.



Taking the strength of the plate at.....100
The strength of the double-riveted joint would then be 70
And the strength of the single-riveted would be.....56

Fig. 2.

HAND- AND MACHINE-RIVETING.

The two methods most generally employed in uniting the riveted seams of steam-boilers are what are termed machine- and hand-riveting. In the former process, the rivet is upset with a single blow; while in the latter, the material is spread or distributed by

a series of blows from hand-hammers. In the process of hand-riveting, the heads are rarely finished till the iron is cool enough to crystallize or crack under the head by the heavy blows of the hammer, and if the material be not of superior quality, will frequently snap off under rough usage.

The evil of the rivet not filling the hole well is sometimes aggravated in hand-work by the blows being dealt on the circumference of the point, in order to form a shoulder speedily to resist the hammering, instead of letting them fall dead on the point, which should tend to make the rivet first fill the hole before the shoulder is formed. The advantage of machine-riveting is that the machine upsets the rivet and closes up the hole better than hand-riveting, as the dead, heavy pressure is exerted through the whole mass of the rivet, and the effect is not concentrated upon the point, as it must be with a succession of light, sharp blows from a hammer. Then again, as the piston of the machine is not limited in its movements, it will follow the rivet home, drawing the plates well together, filling the holes, and making the work equally good, whether the rivet is half an inch too long or half an inch too short, thus accomplishing what no workman could possibly do.

In machine-riveting, the heading is done on the "capping" system, thus gathering the metal together instead of scattering it, as is the case with

the hand hammer. When it becomes necessary to take work apart, where the rivets have been driven, it is shown that the holes are thoroughly filled, and it is also found almost impossible to dislodge the rivets from the holes, while the holes were not more stretched than if the riveting had been done by hand. The shearing strain is less on machine-riveted joints than on those riveted by hand, on account of the compactness of the rivets in the holes, and the great friction between the sheets at the lap, induced by the power of the machine. Another great advantage of steam-riveting is its quickness and cheapness, while the rivets and plates are left soft and free from any crystallization. The general conclusion drawn from practical experience and observation is, that for good, sound boiler-work *machine-riveting* is the best.

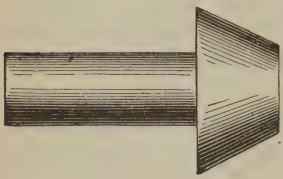
COUNTER-SUNK RIVETS.

Counter-sunk rivets are generally tighter than any other form of rivet, because counter-sinking the hole is really facing it; and the counter-sunk rivet is, in point of fact, made on a faced joint. But counter-sinking the hole also weakens the plate, inasmuch as it takes away a portion of the metal, and should only be resorted to where necessary, — such as around the fronts of furnaces, the flanges inside of combustion-chambers, and the bottom flanges of

steam-chests. In these places it is by no means detrimental; but no part of the shell of a boiler, except those already mentioned, should be counter-sunk.

RIVETS.

The rivet is the means most generally, if not altogether, employed for uniting the seams of steam-boilers; and it may be taken as a rule, that in any but the best class of work the rivet is stronger than the plate section between the holes. In old boilers particularly, the plates at the joints are generally found to be much more brittle than the rivets, and the rivets, except at the heads, will escape corrosion, where the plate may suffer severely. It has been found by experiment that the strength of rivets of various sizes and descriptions in ordinary riveted work averaged 37,640 lbs. for single shear, and 34,000 lbs. for double shear per square inch of sectional area. The shearing strength of iron rivets with thin steel plates has been found to be less than with plates of the same strength. This is probably due to the harder steel cutting into the iron of the rivet. The average of eight experiments with steel plates and iron rivets gave 37,000 lbs. per square inch.



The strength of riveted seams may be calculated by *Multiplying the area in square inches of one rivet by the number of rivets, and the product by the strength of the metal to resist shearing.*

TABLE

SHOWING DIAMETER AND PITCH OF RIVETS FOR DIFFERENT THICKNESSES OF PLATE.

Single-Riveted Seams.			Double-Riveted Seams.		
Thickness of Plate.	Diameter of Rivet.	Pitch.	Thickness of Plate.	Diameter of Rivet.	Pitch.
$\frac{1}{4}$ in.	$\frac{1}{2}$ in.	$1\frac{1}{4}$ in.	$\frac{1}{4}$ in.	$\frac{1}{2}$ in.	$1\frac{3}{4}$ in.
$\frac{5}{16}$ "	$\frac{5}{8}$ "	$1\frac{5}{8}$ "	$\frac{5}{16}$ "	$\frac{5}{8}$ "	$2\frac{1}{4}$ "
$\frac{3}{8}$ "	$\frac{11}{16}$ "	$1\frac{3}{4}$ "	$\frac{3}{8}$ "	$\frac{11}{16}$ "	$2\frac{1}{4}$ "
$\frac{7}{16}$ "	$\frac{3}{4}$ "	$1\frac{7}{8}$ "	$\frac{7}{16}$ "	$\frac{3}{4}$ "	$2\frac{1}{2}$ "
$\frac{1}{2}$ "	$\frac{3}{4}$ "	$1\frac{7}{8}$ "	$\frac{1}{2}$ "	$\frac{3}{4}$ "	$2\frac{1}{2}$ "
$\frac{9}{16}$ "	$\frac{7}{8}$ "	$2\frac{1}{8}$ "	$\frac{9}{16}$ "	$\frac{7}{8}$ "	$2\frac{3}{4}$ "
$\frac{5}{8}$ "	$\frac{7}{8}$ "	$2\frac{1}{8}$ "	$\frac{5}{8}$ "	$\frac{7}{8}$ "	$2\frac{3}{4}$ "
$\frac{11}{16}$ "	$\frac{7}{8}$ "	$2\frac{1}{4}$ "	$\frac{11}{16}$ "	$\frac{7}{8}$ "	$2\frac{7}{8}$ "
$\frac{3}{4}$ "	1 "	$2\frac{1}{4}$ "	$\frac{3}{4}$ "	1 "	$3\frac{1}{4}$ "
$\frac{13}{16}$ "	1 "	$2\frac{1}{4}$ "	$\frac{13}{16}$ "	1 "	$3\frac{1}{4}$ "
$\frac{7}{8}$ "	1 "	$2\frac{1}{4}$ "	$\frac{7}{8}$ "	1 "	$3\frac{1}{4}$ "
$\frac{15}{16}$ "	$1\frac{1}{8}$ "	$2\frac{1}{2}$ "	$\frac{15}{16}$ "	$1\frac{1}{8}$ "	$3\frac{1}{4}$ "
1 "	$1\frac{1}{8}$ "	$2\frac{1}{2}$ "	1 "	$1\frac{1}{8}$ "	$3\frac{1}{2}$ "

STRENGTH OF STAYED AND FLAT BOILER SURFACES.

The sheets that form the sides of fire-boxes are necessarily exposed to a vast pressure, therefore some expedient has to be devised to prevent the metal at these parts from bulging out. Stay-bolts

are generally placed at a distance of $4\frac{1}{2}$ inches from centre to centre, all over the surface of fire-boxes, and thus the expansion or bulging of one side is prevented by the stiffness or rigidity of the other. Now, in an arrangement of this kind, it becomes necessary to pay considerable attention to the tensile strength of the stay-bolts employed for the above purpose, since the ultimate strength of this part of the boiler is now transferred to them, it being impossible that the boiler-plates should give way unless the stay-bolts break in the first instance.

Accordingly, all the experiments that have been made, by way of test, of the strength of stay-bolts, possess the greatest interest for the practical engineer. Mr. Fairbairn's experiments are particularly valuable. He constructed two flat boxes, 22 inches square. The top and bottom plates of one were formed of $\frac{1}{2}$-inch copper, and of the other $\frac{3}{8}$-inch iron. There was a $2\frac{1}{2}$-inch water space to each, with $\frac{3}{8}$-inch iron-stays screwed into the plates, and riveted on the ends. In the first box, the stays were placed five inches from centre to centre, and the two boxes tested by hydraulic pressure.

In the copper box, the sides commenced to bulge at 450 pounds pressure to the square inch; and at 810 pounds pressure to the square inch the box burst, by drawing the head of one of the stays through the copper plate. In the second box, the stays were placed at 4-inch centres; the bulging

commenced at 515 pounds pressure to the square inch. The pressure was continually augmented up to 1600 pounds. The bulging between the rivets at that pressure was one-third of an inch; but still no part of the iron gave way. At 1625 pounds pressure the box burst, and in precisely the same way as in the first experiment — one of the stays drawing through the iron plate, and stripping the thread in the plate. These experiments prove a number of facts of great value and importance to the engineer. In the first place, they show that, with regard to iron stay-bolts, their tensile strength is at least equal to the grip of the plate.

The grip of the copper bolt is evidently less. As each stay, in the first case, bore the pressure on an area of $5 \times 5 = 25$ square inches, and in the second on an area of $4 \times 4 = 16$ square inches, the total strains borne by each stay were, for the first, $815 \times 25 = 20{,}375$ pounds on each stay; and for the second, $1625 \times 16 = 26{,}000$ pounds on each stay. These strains were less, however, than the tensile strength of the stays, which would be about 28,000 pounds. The properly stayed surfaces are the strongest part of boilers, when kept in good repair.

BOILER-STAYS.

Advantage is usually taken of the self-supporting property of the cylinder and sphere, which enables

them, in most cases, to be made sufficiently strong without the aid of stays, or other support. But the absence of this self-sustaining property in flat surfaces necessitates their being strengthened by stays, or other means. Even where a flat or slightly dished surface possesses sufficient strength to resist the actual pressure to which it is subjected, it is yet necessary to apply stays to provide against undue deflection or distortion, which is liable to take place to an inconvenient degree, or to result in grooving long before the strength of the plates or their attachments is seriously taxed.

Boiler-stays, in any case, are but substitutes for real strength of construction. They would be of no service applied to a sphere subject to internal pressure; and the power of resistance would be exactly that of the metal to sustain the strain exerted upon all its parts alike. The manner in which stays are frequently employed renders them a source of weakness rather than an element of strength. When the strain is direct, the power of resistance of the stay is equal to the weight it would sustain without tearing it asunder; but when the position of the stay is *oblique* to the point of resistance, any calculation of their theoretic strength or value is attended with certain difficulties. All boilers should be sufficiently stayed to insure safety, and the material of which they are made, their *shape, strength, number, location, and mode of attachment* to the boiler, should be

all duly and intelligently considered. Boiler-stays should never be subjected to a strain of more than one-eighth of their breaking strength. The strength of boiler-stays may be calculated by *multiplying the area in inches, between the stays, by the pressure in pounds per square inch.*

STAY-BOLTS.

In the choice of material for stay-bolts for the furnaces of marine boilers and locomotives, and even stationary engines, there are other considerations besides that of strength alone. Iron would undoubtedly be superior to any other material that could be employed for that purpose, if strength and its facilities for working were the only objects to be considered; but there are two evils that limit the usefulness of iron stay-bolts: *first*, they crystallize; *second*, they corrode. In either case they are likely to snap in half under any extraordinary pressure — that is, at the very moment when their services are most needed.

Copper has neither of these faults. It has extreme tenacity up to a certain point of its working, and hot water does not corrode it in the least. Some engineers have tried the effect of placing iron stays in two or three of the upper rows, and copper in the lower rows, where the corrosive influence of the water is more powerful. But this is opposed to all

practical experience, since the upper bolts are always found to break most frequently from the superior expansion of the inner plate; hence, the material that will endure the most bending should be employed for them.

Steel stay-bolts have been occasionally employed with good effect. When they have a spring temper, they seem to stand the effect of contraction and expansion better than any other material, since their small diameter and great elasticity permit them to conform to all moderate variations in the boiler caused by ordinary degrees of temperature. The safe working strength of copper, iron, and steel stay-bolts may be estimated at about one-fifth of the ultimate strength, which for steel is 80,000, iron 60,000, and copper 32,000; but if the screws are cut within the original diameter of the bolt, one-tenth of the working strength must be deducted.

The following table shows the result of experiments on iron and copper stay-bolts screwed and riveted into iron and copper plates. *First*, a $\frac{3}{4}$-inch iron stay with enlarged head, screwed and riveted into a $\frac{5}{8}$-inch iron plate, failed by breaking through the shank with 25,000 pounds, the screw and plate remaining uninjured. *Second*, a similar arrangement, but with a copper plate, failed with a load of 21,400 pounds, the head tearing off, and the copper threads stripping. *Third*, a $\frac{3}{4}$-inch iron stay with enlarged end screwed into a $\frac{5}{8}$-inch copper plate, and not

riveted, was drawn out of the plate by 16,200 pounds, the copper thread stripping. *Fourth*, a $\frac{3}{4}$-inch copper stay with enlarged end, screwed and riveted into a $\frac{3}{8}$-inch copper plate, broke through the shank with 14,400 pounds, after stretching $\frac{9}{16}$ of an inch.

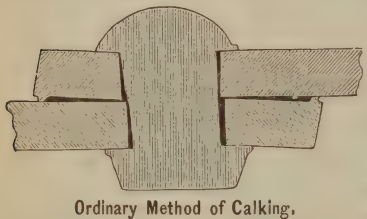
	Breaking Weight in Pounds.	Strength distributed over 25 ins. area would give lbs. per sq. in.	Strength distributed over 16 ins. area would give lbs. per sq. in.
1st. Iron into iron screwed and riveted...	25,000	1,000	1,563
2d. Iron into copper screwed and riveted...	21,400	856	1,338
3d. Iron into copper screwed only.....	16,200	648	1,013
4th. Copper into copper screwed and riveted.	14,400	576	900

CALKING.

The object of calking is to bring together the seams of a boiler, after riveting, so that they may be perfectly steam- and water-tight. This is done by using a sharp tool ground to a slight angle. The edge of the plates being first chipped or planed to an angle of about 110°, the calking-tool is then applied to the lower edge of the chipped or planed angle, in order to drive or upset the edge, thus bringing the plates together and rendering the joint, to all appearances, perfectly steam-tight, and able to resist

the internal pressure brought to bear upon this particular point.

The purely mechanical skill required to enable a person to join together pieces of metal, and thereby form a steam-tight and water-tight joint, was all that was heretofore considered necessary, as it had been almost universally thought that little more than this was needed, and that, provided the joint was tightly and well calked, or, in other words, "made a good job of," was all that was required. But, unfortunately, this is but a small portion of the knowledge that should be possessed by persons who turn their attention to this subject, and experience has shown that persons engaged in this kind of employment should possess a very different kind of knowledge, otherwise the best efforts of the manufacturer of the material and the boiler-maker will be rendered useless.



Ordinary Method of Calking.

It is well known that the use of a hammer on wrought-iron will granulate, or harden, it to such an extent as to make it almost as hard as steel. Now, the angled tool before mentioned, through its action (in the process of calking) upon the lower edge of the chipped plate, causes a granulation of that plate;

while the under one is much softer, in consequence of not being exposed to the action of the tool, consequently the skin, or outer surface of the softer material, is indented or cut.

A boiler may be constructed by parties of high repute, be made of the best material, and, to all appearance, be capable of standing any test that may be applied to prove its safety, and yet its durability may be very limited, or it may collapse or explode soon after being put in use, for the simple reason that a cause existed from the very first which could not be seen, and which no test could point out, and that cause was the grooving or indentation made by the calking, which became larger and larger through corrosion, expansion, and contraction, thus rendering the plates unfit to resist the strain, which must eventually induce rupture or explosion, resulting in loss of life and destruction of property. This tendency to weaken the plates of steam-boilers, by the present mode of calking, may be illustrated by very familiar examples.

When a blacksmith desires to break his bar of iron to a given length, he first cuts around the bar, weakening it. The breaking is then easily accomplished — frequently with one blow. A glazier similarly uses his diamond. Now, if a bar of iron, which has not been cut, be taken and submitted to blows, in a majority of cases it will bend to a right angle or more without showing any fracture. The explana-

tion of this is, that by cutting a channel through the outer layer of fibre, the strain is confined to the point where the channel is cut. The fibre on either side, to the depth of the channel, is not acted upon at all, and exerts no influence as a protection to the underlying layers of fibre. Hence, when the blow is received, the effect is confined to the channel, and the fibre, having little or no opportunity to protect itself, breaks short off. These illustrations are perfectly analogous to that of the cutting or indentation made by the old-fashioned calking-tool.

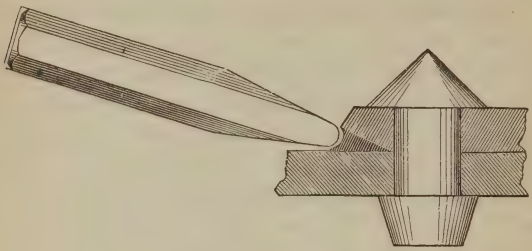
On examination, steam-boilers are frequently found to be fractured along the edge of the outer lap of the sheet, both transversely and longitudinally, in consequence of a channel being entirely cut through the skin of the iron by the calking-tool, thus rendering the plate weak at the point of the greatest strain. The force to act is ever present; the iron is already strained, as, by bending a sheet of iron to make a required circle, the fibres of the iron composing the outer circumference must, of necessity, be stretched; and, by imperfect bending, will be stretched laterally as well as longitudinally, while the fibres of the iron composing the inner circumference are upset, and, if badly welded in the act of manufacture, pucker, thereby exposing the inside particles of the iron to the corrosive action of the acids in the water, producing honey-combing. Thus everything is ready for the cutting or grooving to be made — both the

strain on the outer, and the puckering on the inner, circumference. It then becomes only a mere question of time as to the result.

Very few, except those familiar with the laws of steam, have any idea of the immense pressure exerted on the shells of steam-boilers under pressure; and when we consider that this immense pressure is brought to bear along the lap of the joints — the points deviating farthest from the true cylindrical form — the importance of having the iron not only of good quality, but free from the defects induced by inferior calking, must at once be admitted. Immense sums of money have been expended in experiments, with the object of ascertaining, if possible, the cause of boiler explosions, which, if conducted by competent persons, might have proved, in many instances, to be the result of a mischievous system of calking.

The cut on page 308 represents an improved method of calking, which is acknowledged by competent parties to be one of the most important improvements ever made in the construction of steam-boilers. It is the invention of James W. Connery, foreman of the Boiler Department at the Baldwin Locomotive Works, Philadelphia, and is known as Connery's Concave Calking. By this method, the dangers to life and property induced by the old system of calking are entirely obviated, as even the uninitiated cannot dent or gall the plates

with Connery's Patent Calking; the importance of which will be appreciated by all steam-users, more especially when it is known that it is impossible, for



Connery's Concave Calking.

even the most skilful boiler-maker, to calk a boiler with the old-fashioned calking-tools without permanent injury to the plates.

TESTING-MACHINES.

There is at present in this country a great need of cheap, simple, and reliable machinery for the purpose of testing the tensile strength of metals, particularly boiler-plate; as it is of great importance to steam-users and the public to know exactly what strain iron of a certain kind or quality will bear without permanent set or fracture. When a boiler explodes, it is of great service to be able to test the tensile strain of the metal torn asunder, that some idea of the force exerted may be estimated, and also

to know whether iron that has been subjected to heavy strains for a number of years has become "fatigued" or weakened.

There are few machines in this country adapted to this business, and these are very expensive. The expense attending their construction, and the comparatively little use to which they are put, have, without doubt, stood in the way of their construction. If manufacturers and users of iron and other metals fully appreciated their value, they would be more frequently met with. The materials for machines should be tested; and a proper understanding of the exact strength which this material will sustain would, no doubt, often lead to improvement in design and construction. In some cases, the whole machine would be lighter, while in others it would possess proportions better adapted to sustain the heavy strains to which it may be subjected.

FEED-WATER HEATERS.

Inattention to the temperature of feed-water for boilers is entirely too common, as the saving in fuel that may be effected by thoroughly heating the feed-water — by means of the exhaust-steam in a properly constructed heater — would be immense, as may be seen from the following facts:

A pound of feed-water entering a steam-boiler at a temperature of 50° Fah., and evaporating into

steam of 60 pounds pressure, requires as much heat as would raise 1157 pounds of water 1 degree. A pound of feed-water raised from 50° Fah. to 220° Fah. requires 987 thermal units of heat, which, if absorbed from exhaust-steam passing through a heater, would be a saving of 15 per cent. in fuel. Feed-water, at a temperature of 200° Fah., entering a boiler, as compared, in point of economy, with feed-water at 50°, would effect a saving of over 13 per cent. in fuel; and with a well-constructed heater there ought to be no trouble in raising the feed-water to a temperature of 212° Fah.

If we take the normal temperature of the feed-water at 60°, the temperature of the heated water at 212°, and the boiler pressure at 20 pounds, the total heat imparted to the steam in one case is 1192.5° — 60° = 1132.5°, and in the other case 1192.5° — 212° = 980.5°, the difference being 152°, or a saving of $\frac{1}{1}\frac{5}{1}\frac{2}{3}\frac{2}{2}\frac{}{.5} = 13.4$ per cent. Supposing the feed-water to enter the boiler at a temperature of 32° Fah., each pound of water will require about 1200 units of heat to convert it into steam, so that the boiler will evaporate between $6\frac{2}{3}$ and $7\frac{1}{2}$ pounds of water per pound of coal. The amount of heat required to convert a pound of water into steam varies with the pressure, as will be seen by the following table:

TABLE

SHOWING THE UNITS OF HEAT REQUIRED TO CONVERT ONE POUND OF WATER, AT THE TEMPERATURE OF 32° FAH., INTO STEAM AT DIFFERENT PRESSURES.

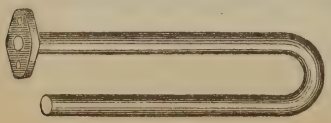
Pressure of Steam in Lbs. per Sq. Inch by Gauge.	Units of Heat.	Pressure of Steam in Lbs. per Sq. Inch by Gauge.	Units of Heat.
1	1,148	110	1,187
10	1,155	120	1,189
20	1,161	130	1,190
30	1,165	140	1,192
40	1,169	150	1,193
50	1,173	160	1,195
60	1,176	170	1,196
70	1,178	180	1,198
80	1,181	190	1,199
90	1,183	200	1,200
100	1,185		

If the feed-water has any other temperature, the heat necessary to convert it into steam can easily be computed. Suppose, for instance, that its temperature is 65°, and that it is to be converted into steam having a pressure of 80 pounds per square inch. The difference between 65 and 32 is 33; and subtracting this from 1181 (the number of units of heat required for feed-water having a temperature of 32°), the remainder, 1148, is the number of units for feed-water with the given temperature. Yet it must be understood that any design of heater that offers such resistance to the free escape of the exhaust-steam as to neutralize the gain that would otherwise be ob-

tained from its use, ought to be avoided, as the loss occasioned by back pressure on the exhaust, in many instances, counteracts the advantages derived from the heating of the feed-water.

It is a common practice on steamships to heat the feed-water to 135° or 140° before sending it into the boiler. Where the jet condenser is used, this extra heat is derived from the blow-water; but as this means of heating is not available with the surface condenser, it is generally derived from a water-jacket surrounding the smoke-stack, or a spiral pipe within the stack. But although any heat imparted to the feed-water is a clear gain, yet the cost, complication, and danger of these arrangements generally overbalance the benefits derived from their use.

The feed-water should be sent into the boiler as hot as possible, as, if it be forced in at a low temperature, it will impinge on that portion of the boiler with which it comes in contact; and, as a result of the continual expansion and contraction induced by the varying temperature of the water, the boiler is liable to crack and become leaky. Where economy of fuel is no object, as is often the case at coal-mines, saw-mills, and wood-working establishments, a very inexpensive way of averting the disastrous effects of pumping cold water into boilers is to



Heater Pipe.

introduce the feed-pipe into the back end of the boiler, carrying it forward about three-quarters the length of the boiler, and then returning it to the back end, where the water is discharged into the boiler. By this arrangement the water will have a temperature nearly equal to that of the water in the boiler when discharged from the pipe.

Open feed-water heaters, though very efficient, are nevertheless objectionable, and should be avoided whenever any better arrangement is attainable. The grease from the cylinder mixes with the feed-water in such heaters, and on being carried into the boiler combines with the carbonate of lime, sinks to the plates when the boilers are at rest, and is rarely ever afterwards moved by the circulation of the water, or even the most active boiling currents. By contact with the plates the water is kept from their surface, and the free transmission of the heat interfered with, which induces over-heating and burning of the plates.

All feed-water heaters should be provided with the means of ascertaining the temperature of feed-water. This might be done by placing a hollow plug in a T on the feed-pipe, between the heater and the boiler, into which the bulb of a thermometer might be inserted at any time; and as the plug would be exposed to the action of the water in its passage from the heater to the boiler, its temperature might be easily ascertained.

GRATE-BARS.

Perfect combustion is the starting-point in the generation of steam; the conversion of coal and air into heat must be the first process, and the second is to apply that heat with full effect to the boiler. The oxygen of the air is the only supporter of combustion; and the rate of combustion produced, and the amount of heat generated in the furnace, depend on the quantity of air supplied; and the quantity of air admitted depends on the size of the opening through which it passes. Then, as a matter of course, the grate-bars offering the least obstruction to the air passing through them, and affording the largest area for the air combined, with an equal distribution of the same, must be the best adapted for the purposes of combustion.

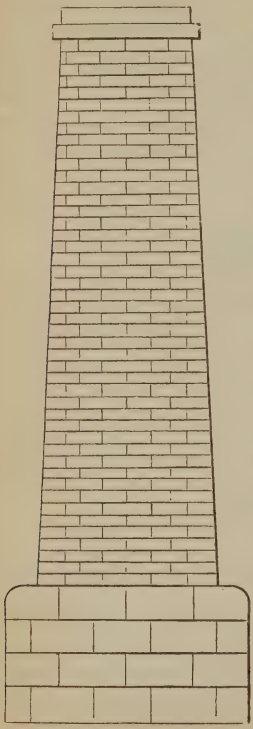
The failure of grate-bars is due mainly to three different causes — breaking, warping, and burning out; consequently, grate-bars, to be durable and efficient, should have a narrow surface exposed to the fire, the spaces for admitting the air being numerous and well distributed. The metal constituting the bar should be distributed in the best possible manner, to relieve the grate from all undue strain arising from unequal expansion and contraction; there should also be considerable depth, in order that the lower edges may keep cool, and prevent the possibility of warping or twisting. Grate-bars of good

design and proportions are frequently ruined by being exposed to a white heat, whenever a fresh fire is started, whereas, by distributing a thin layer of fresh coal over their surface before the shavings and wood are applied, they may be preserved intact for years. The grate-bar has not heretofore received the consideration from engineers and steam-users which its importance, in an economical point of view, so eminently deserves.

CHIMNEYS.

The object of a chimney is to convey away the smoke, and to produce a draught — that is, a current of fresh, dry air through the coals on the grate; this draught is produced by the difference in the specific gravity of the air inside and outside of the chimney. If the quality of the gases inside and outside were always the same, formulæ could be established for the size of chimneys with a considerable degree of accuracy. The gases inside of a chimney are generally composed of atmospheric air, free nitrogen, carbonic acid, carbonic oxide, steam, free hydrogen, free carbon, sulphurous acid, and other elements. If the relative amount of these gases, and their temperature, were always the same, there would not be much difficulty in determining the proportions; but as these conditions are continually changing, as well by the gradual consumption

of the coal on the grate as by the management of the party in charge, it is impossible to arrive at any exact or definite conclusion. The air outside the chimney is also continually undergoing changes, produced by moisture, temperature, density, etc.



For stationary and marine boilers the chimneys are generally of a uniform height, arising from the nature of the structures with which they are connected, and hence the approximate amount of combustion on a square foot of grate-surface, and the resulting evaporation of water per hour, are pretty well known from practical observations. For marine boilers, the general rule is to allow 14 square inches area of chimney for each nominal horse-power. For stationary boilers, the area of the chimney should be one-fifth greater than the combined area of all the flues or tubes. In boilers

provided with any other means of draught, such as a steam-jet or a fan-blower, the dimensions of the chimney are not so important as it is in cases where the draught is produced solely by the chimney.

Rule *for finding the Required Area of Chimney for any Boiler.* — Multiply the nominal horse-power of the boiler by 112, and divide the product by the square root of the height of the chimney in feet. The quotient will be the required area in square inches.

TABLE

SHOWING THE PROPER DIAMETER AND HEIGHT OF CHIMNEY FOR ANY KIND OF FUEL.

Nominal Horse-power of Boiler.	Height of Chimney in Feet.	Inside Diameter at Top.
10	60	1 foot 2 inches.
12	75	1 " 2 "
16	90	1 " 4 "
20	99	1 " 5 "
30	105	1 " 9 "
50	120	2 feet 2 "
70	120	2 " 6 "
90	120	2 " 10 "
120	135	3 " 2 "
160	150	3 " 7 "
200	165	3 " 11 "
250	180	4 " 4 "

TABLE

SHOWING HEIGHTS OF CHIMNEYS FOR PRODUCING CERTAIN RATES OF COMBUSTION PER SQUARE FOOT OF AREA OF SECTION OF THE CHIMNEY.

Heights in Feet.	Pounds of Coal Burned per Hour per Square Foot of Section of Chimney.	Pounds of Coal Burned per Hour per Square Foot of Grate, the Ratio of Grate to Section of Chimney being 8 to 1.
20	60	7.5
25	68	8.5
30	76	9.5
35	84	10.5
40	93	11.6
45	99	12.4
50	105	13.1
55	111	13.8
60	116	14.5
65	121	15.1
70	126	15.8
75	131	16.4
80	135	16.9
85	139	17.4
90	144	18.0
95	148	18.5
100	152	19.0
105	156	19.5
110	160	20.0

Though the above Table was arranged from data collected from what were considered reliable experiments, yet it may be said to be only approximately correct, as the conditions existing in different chimneys and furnaces vary so much that no theoretical formulæ will give results which can be relied upon as strictly correct. According to the experiments

of Mr. Isherwood, the best proportion for the draught area is $\frac{1}{8}$ of the area of the grate. Many constructors, however, make it greater, amounting in some cases to $\frac{1}{7}$ and $\frac{1}{6}$. Others make it less, $\frac{1}{10}$ being not uncommon. But experience has shown $\frac{1}{8}$ to be the most practical proportion, and the one capable of producing the most satisfactory results.

SMOKE.

Ever since the days of Watt, the consumption of smoke has attracted the attention of scientists, inventors, and engineers, but, hitherto, without any very practical results, as the methods that offered the most plausible solution of the problem involved in the burning of smoke have invariably failed to produce such results as would warrant their adoption and general use. A uniform supply of fuel to the furnace, and the introduction of air above the fire, were advocated as furnishing a remedy for the loss occasioned by smoke; but the former was, in most cases, found impracticable and inconvenient on account of the varying circumstances involved in the management of furnaces; whilst the latter was frequently productive of more waste than that occasioned by smoke, in consequence of the current of cool air above the fire being constant, and the quantity of fuel on the grate, and the temperature of the furnace, varying very much.

From numerous smoke-stacks throughout the land can great volumes of smoke, as black as midnight, be seen, at almost all times, rolling upward, carrying with them, to all appearance, the most valuable portions of the fuel. But it must be understood that all that comes out of the chimney is not smoke by any means. Bituminous coal contains from five to six per cent. of hydrogen, which unites with the oxygen necessary to combustion, and constitutes water. A ton of bituminous coal will make nearly one-third of a ton of water in the form of steam. That this steam is black, does not necessarily indicate the presence of much carbon, as a grain of soot, if distributed evenly in fine particles through a cubic foot of steam, would color it blacker than the ace of spades. Now it requires no argument to show that this steam cannot be burned. It may be condensed by being made to pass through tubes kept at a low temperature, though a draught could only be maintained artificially under these conditions.

Were it not for this mass of steam, the carbon would soon fall as a cloud of black dust; but, being intimately and atomically mixed with the large volume of steam from the furnace, it is carried along by the atmosphere, only differing in color, like the cloud of steam we see issuing from the chimney of a locomotive when in action. With furnaces properly constructed, in which a thorough mixture of the

heated gases with air may be effected, as in the Bunsen burner, smoke might be partially consumed; but the conditions under which this successful mixture of the air and gases may be effected are rarely ever found in the furnace of a steam-boiler, as the temperature is continually varying, while the quantity of air that passes into the furnace is constant. The volume of smoke may be diminished in ordinary furnaces by supplying the fuel in small quantities to one side of the furnace at a time, or by placing the fuel inside of the furnace door, then, when the smoke is consumed, move the fuel back and replace it with a fresh supply. This necessitates the continual opening and closing of the furnace door, which admits the cold air in such quantities as to lower the temperature in the furnace and defeat the object intended to be accomplished. As an object of comfort and convenience, the successful consumption of smoke is very much to be desired, but when once formed, smoke cannot be burned by any known process or device.

CONTRIVANCES FOR INCREASING DRAUGHT AND ECONOMIZING FUEL IN BOILER FURNACES.

Where space is of no object, a large boiler, large grate, and high stack afford the best advantages for the combustion of the fuel employed for the generation of steam; but whenever, on the contrary,

space and weight have to be economized, as in the case of locomotive and marine boilers, some means of increasing the draught and intensifying combustion becomes indispensable. For years, the question whether this object can be effected by means of water or steam has agitated the practical and scientific men of the country, many engineers and others affirming that water does increase the heat of a fire, while almost all men of thorough scientific training hold that such an idea contradicts well known and recognized laws.

The idea of a jet or jets of steam above or below the grate is very old, and descriptions of such appliances are to be found in various publications on the burning of smoke; but the statements on this subject are very contradictory, and the benefits to be derived from the use of the steam-jet are as undecided at the present day as in the days of Watt. The principal benefit claimed for the steam-jet is, that for every ton of oxygen required for the combustion of the fuel, four tons of useless nitrogen have to be heated from the ordinary temperature of the air to that at which the gases escape into the chimney; whereas, by the use of the steam-jet, we increase the quantity of oxygen, and are enabled to intensify the combustion by diminishing the quantity of air admitted, thus utilizing the heat that would otherwise be lost in raising the temperature of the useless nitrogen to that of the escaping gases; or, in other words,

we will suppose that the incandescent coal derives a portion of the oxygen required for its combustion from the water, it is obvious that the amount of air that is required will be lessened in due proportion.

A great number of experiments, both in this country and Europe, have shown that there is nothing, in an economical point of view, to be gained by the use of either steam or water, either in the increase of the draught of ordinary furnaces or in intensifying combustion, as, while the draught may be sensibly increased, the consumption of fuel is not materially lessened, proof of which may be found in the fact that wherever such means are tried, they are soon allowed to fall into disuse, if not entirely abandoned. For factory purposes, or where it becomes necessary to consume a large quantity of fuel on a small area of grate, the *fan-blower* is undoubtedly the most practical, efficient, and convenient, as it not only intensifies the combustion, but greatly increases the quantity of available heat. The expense incurred in its employment is confined simply to the cost of the fan itself.

TABLE

SHOWING THE ACTUAL EXTENSION OF WROUGHT-IRON AT VARIOUS TEMPERATURES.

Deg. of Fah.	Length.	
32°	1.	
212	1.0011356	
392	1.0025757	Surface becomes straw colored, deep yellow, crimson, violet, purple, deep blue, bright blue.
672	1.0043253	
752	1.0063894	
932	1.0087730	Surface becomes dull, and then bright red.
1112	1.0114811	
1652	1.0216024	Bright red, yellow, welding heat, white heat.
2192	1.0348242	
2732	1.0512815	
2912	Cohesion destroyed. Fusion perfect.	

Linear Expansion of Wrought-iron.—The linear expansion which a bar of wrought-iron undergoes, according to Daniell's pyrometer, when heated from the freezing- to the boiling-point, or from 32° to 212° Fah., is about $\frac{1}{850}$ of its length; at higher temperatures, the elongation becomes more rapid. Thus, it will be seen how sensible a change takes place when iron undergoes a variation of temperature. A bar of iron, 10 feet long, subject to an ordinary change of temperature of from 32° to 180° Fah., will elongate more than $\frac{1}{8}$ of an inch, or sufficient to cause fracture in stone work, strip the thread of a screw, or endanger a bridge, floor, roof, or truss, or even push out a wall if brought in contact with it.

The expansion of volume and surface of wrought-iron is calculated by taking the linear expansion as unity; then, following the geometrical law, the superficial expansion is twice the linear, and the cubical expansion is three times the linear.

Wrought-iron will bear on a square inch, without permanent alteration, 17,800 pounds, and an extension in length of $\frac{1}{1400}$. Cohesive force is diminished $\frac{1}{3000}$ by an increase of 1 degree of heat.

Compared with cast-iron, its strength is 1.12 times, its extensibility 0.86 times, and its stiffness 1.3 times.

Cast-iron expands $\frac{1}{16200}$ of its length for 1 degree of heat; the greatest change in the shade, in this climate, is $\frac{1}{1170}$ of its length; exposed to the sun's rays, $\frac{1}{1000}$.

Cast-iron shrinks, in cooling, from $\frac{1}{85}$ to $\frac{1}{98}$ of its length.

Cast-iron is crushed by a force of 93,000 pounds upon a square inch, and will bear, without permanent alteration, 15,300 pounds upon a square inch.

To find the surface dilatation of any particular article, double its linear dilatation; and to find the dilatation in volume, triple it. To find the elongation in linear inches, per linear foot, of any particular article, multiply its respective linear dilatation, as given in the table, by 12.

TABLE

SHOWING THE LINEAR DILATATION OF SOLIDS BY HEAT.

Length which a Bar Heated to 212° has greater than when at the Temperature of 32°.	
Brass, cast	0018671
Copper	0017674
Gold	0014880
Iron, cast	0011111
Iron, wrought	0012575
Silver	0020205
Steel	0011898

TABLE

DEDUCED FROM EXPERIMENTS ON IRON PLATES FOR STEAM-BOILERS, BY THE FRANKLIN INSTITUTE, PHILADA.

Iron boiler-plate was found to increase in tenacity, as its temperature was raised, until it reached a temperature of 550° above the freezing-point, at which point its tenacity began to diminish.

At 32° to 80°	tenacity is	56,000 lbs.,	or $\frac{1}{7}$ below its maximum.
" 570°	"	" 66,000 "	the maximum.
" 720°	"	" 55,000 "	the same nearly as at 30°.
" 1050°	"	" 32,000 "	nearly $\frac{1}{2}$ the maximum.
" 1240°	"	" 22,000 "	nearly $\frac{1}{3}$ the maximum.
" 1317°	"	" 9,000 "	nearly $\frac{1}{7}$ the maximum.

It will be seen by the above table that if a boiler should become overheated, by the accumulation of scale on some of its parts, or an insufficiency of water, the iron would soon become reduced to less than one-half its strength.

TABLE

SHOWING THE RESULTS OF EXPERIMENTS MADE ON DIFFERENT BRANDS OF BOILER IRON AT THE STEVENS INSTITUTE OF TECHNOLOGY, HOBOKEN, N. J.

Thirty-three experiments were made upon the iron taken from the exploded steam-boiler of the ferry-boat "Westfield." The following were the results:

	Lbs. per. sq. in.
Average breaking weight	41,653
16 experiments made upon high grades of American boiler-plate.	
Average breaking weight	54,123
15 experiments made upon high grades of American flange-iron.	
Average breaking weight	42,144
6 experiments made upon English Bessemer steel.	
Average breaking weight	82,621
5 experiments made upon English Lowmoor boiler-plate.	
Average breaking weight	58,984
6 experiments made upon samples of tank iron taken from different manufacturers.	
Average breaking weight No. 1	43,831
" " " No. 2	42,011
" " " No. 3	41,249
2 experiments made on iron taken from the exploded steam-boiler of the Red Jacket.	
Average breaking weight	49,000

It will be noticed that the above experiments reveal a great variation in the strength of boiler-plate of different grades.

TABLE

SHOWING THE WEIGHT OF CAST-IRON BALLS FROM 3 TO 13 INCHES IN DIAMETER.

Dia. in Ins.	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾
Wt. in Lbs.	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼	52½	58	64

Dia. in Ins.	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½	12	13
Wt. in Lbs.	70½	77¼	84¼	92½	100¼	109	118	127½	137¾	148¼	159½	171	183¼	209½	238	302

WEIGHT OF CAST-IRON PLATES PER SUPERFICIAL FOOT AS PER THICKNESS.

Thickness in Inches.....	⅛		¼		⅜		½		⅝		¾		⅞		1	
Weight.....	lbs. 4	oz. 13	lbs. 9	oz. 10	lbs. 14	oz. 8	lbs. 19	oz. 5	lbs. 24	oz. 2	lbs. 29	oz. 0	lbs. 33	oz. 13	lbs. 38	oz. 10

TABLE

SHOWING THE WEIGHT OF ROUND-IRON FROM ½ AN INCH TO 6 INCHES DIAMETER, 1 FOOT LONG.

For Calculating the Weight of Shafting, etc.

Diameter in Inches.	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛
Weight in Lbs.....	¾	1	1½	2	2¾	3½	4¼	5	6	7	8	9½	10½	12

Diameter in Inches.	2¼	2⅜	2½	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞
Weight in Lbs.....	13½	15	16¾	18¼	20	22	24	26	28	30¼	32½	35	37¼	40

Diameter in Inches.	4	4⅛	4¼	4⅜	4½	4⅝	4¾	4⅞	5	5¼	5½	5¾	6
Weight in Lbs.....	42½	45¼	48	50¾	53¾	56¾	60	63	66¾	73¼	80¼	87¾	95½

TABLE

SHOWING THE WEIGHT OF BOILER-PLATES 1 FOOT SQUARE AND FROM $\frac{1}{16}$TH TO AN INCH THICK.

Th. in Ins...	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
Wt. in Lbs. per ft. sq.	$2\frac{1}{2}$	5	$7\frac{1}{2}$	10	$12\frac{1}{2}$	15	$17\frac{1}{2}$	20	$22\frac{1}{2}$	25	$27\frac{1}{2}$	30	$32\frac{1}{2}$	35	$37\frac{1}{2}$	40

TABLE

SHOWING THE WEIGHT OF SQUARE BAR-IRON, FROM $\frac{1}{2}$ AN IN. TO 6 INS. SQUARE, 1 FOOT LONG.

Square.....	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$
Wt. in Lbs.	$\frac{8}{10}$	$1\frac{1}{4}$	2	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$7\frac{1}{2}$	9	$10\frac{1}{2}$	12	$13\frac{1}{2}$	$15\frac{1}{4}$	17	19	22	$23\frac{1}{4}$	$25\frac{1}{2}$	28	$30\frac{1}{2}$	33

Square.....	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{5}{8}$	$4\frac{3}{4}$	$4\frac{7}{8}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	6
Wt. in Lbs.	$35\frac{3}{4}$	$38\frac{1}{2}$	$41\frac{1}{2}$	$44\frac{1}{2}$	$47\frac{1}{2}$	$50\frac{3}{4}$	54	$57\frac{1}{2}$	61	$64\frac{3}{4}$	$68\frac{1}{2}$	$72\frac{1}{2}$	$76\frac{1}{4}$	$80\frac{1}{4}$	$84\frac{1}{2}$	$93\frac{1}{4}$	$102\frac{1}{4}$	$111\frac{3}{4}$	$121\frac{3}{4}$

TABLE

SHOWING THE WEIGHT OF CAST-IRON PIPES, 1 FOOT IN LENGTH, FROM $\frac{1}{4}$ INCH TO $1\frac{1}{4}$ INCHES THICK AND FROM 3 INCHES TO 24 INCHES DIAMETER.

Dia. of Bore in Inches.	Thickness in Inches.								
	$\frac{1}{4}$ Lbs.	$\frac{3}{8}$ Lbs.	$\frac{1}{2}$ Lbs.	$\frac{5}{8}$ Lbs.	$\frac{3}{4}$ Lbs.	$\frac{7}{8}$ Lbs.	1 Lbs.	$1\frac{1}{8}$ Lbs.	$1\frac{1}{2}$ Lbs.
3	$8\frac{1}{2}$	$12\frac{1}{2}$	$17\frac{1}{4}$	$22\frac{1}{4}$	$27\frac{1}{2}$	.....	.....	.....	.....
$3\frac{1}{2}$	$9\frac{1}{4}$	$14\frac{1}{3}$	$19\frac{1}{2}$	$25\frac{1}{4}$	$31\frac{1}{4}$	.....	.....	.....	.....
4	10	$16\frac{3}{4}$	22	$28\frac{1}{2}$	35	.....	.....	.....	.....
$4\frac{1}{2}$	$11\frac{3}{4}$	18	$24\frac{1}{2}$	$31\frac{1}{2}$	$38\frac{3}{4}$	.....	.....	.....	.....
5	13	$19\frac{3}{4}$	27	$34\frac{1}{2}$	$42\frac{1}{4}$	$50\frac{1}{2}$	59	.....	.....
$5\frac{1}{2}$	15	$21\frac{1}{2}$	$29\frac{1}{2}$	$37\frac{1}{2}$	46	$54\frac{3}{4}$	$63\frac{3}{4}$	.....	.....
6	.....	$23\frac{1}{2}$	32	$40\frac{3}{4}$	$49\frac{3}{4}$	59	$68\frac{3}{4}$	$78\frac{3}{4}$	$88\frac{3}{4}$
$6\frac{1}{2}$	.....	$25\frac{1}{4}$	$34\frac{1}{2}$	$43\frac{3}{4}$	$53\frac{1}{2}$	$63\frac{1}{2}$	$73\frac{1}{2}$	$84\frac{1}{4}$	95
7	.....	$27\frac{1}{4}$	$36\frac{3}{4}$	$46\frac{3}{4}$	$56\frac{3}{4}$	$67\frac{3}{4}$	$78\frac{1}{2}$	$89\frac{3}{4}$	$101\frac{1}{4}$
$7\frac{1}{2}$	.....	29	39	50	$60\frac{3}{4}$	72	$83\frac{1}{2}$	$95\frac{1}{4}$	$107\frac{1}{2}$
8	.....	$30\frac{3}{4}$	$41\frac{3}{4}$	53	$64\frac{1}{2}$	$76\frac{1}{4}$	$88\frac{1}{2}$	$100\frac{3}{4}$	$113\frac{1}{2}$
$8\frac{1}{2}$	.....	33	$44\frac{1}{2}$	$56\frac{1}{4}$	$68\frac{1}{4}$	$80\frac{3}{4}$	$93\frac{1}{2}$	$106\frac{1}{2}$	120
9	.....	$34\frac{1}{2}$	$46\frac{3}{4}$	59	$71\frac{3}{4}$	$84\frac{3}{4}$	$98\frac{1}{2}$	$111\frac{3}{4}$	$125\frac{3}{4}$
$9\frac{1}{2}$	.....	$36\frac{1}{4}$	49	62	$75\frac{1}{2}$	89	103	$117\frac{1}{2}$	132
10	.....	$38\frac{1}{4}$	$51\frac{1}{2}$	$65\frac{1}{4}$	$79\frac{1}{4}$	$93\frac{1}{2}$	108	$122\frac{3}{4}$	138
$10\frac{1}{2}$	.....	.....	54	$68\frac{1}{4}$	$82\frac{3}{4}$	$97\frac{3}{4}$	$112\frac{3}{4}$	$128\frac{1}{2}$	$144\frac{1}{4}$
11	.....	.....	$56\frac{1}{2}$	$71\frac{1}{2}$	$86\frac{1}{2}$	102	$117\frac{3}{4}$	134	$150\frac{1}{4}$
$11\frac{1}{2}$	.....	.....	59	$76\frac{1}{4}$	90	$106\frac{1}{4}$	$122\frac{3}{4}$	$139\frac{1}{2}$	$156\frac{1}{2}$
12	.....	.....	$61\frac{1}{4}$	$77\frac{1}{2}$	$93\frac{1}{2}$	$110\frac{1}{2}$	$127\frac{1}{2}$	145	$162\frac{1}{2}$
13	.....	.....	.....	$82\frac{3}{4}$	$101\frac{1}{4}$	$118\frac{1}{4}$	$137\frac{1}{2}$	154	$173\frac{1}{2}$
14	.....	.....	.....	$89\frac{1}{4}$	$108\frac{1}{2}$	$126\frac{1}{2}$	$146\frac{1}{4}$	$165\frac{1}{2}$	$185\frac{1}{4}$
15	.....	.....	.....	$95\frac{1}{4}$	$115\frac{3}{4}$	$135\frac{1}{4}$	$156\frac{1}{4}$	$176\frac{1}{4}$	198
16	.....	.....	.....	.....	$123\frac{1}{4}$	143	166	$187\frac{1}{2}$	$211\frac{1}{4}$
17	.....	.....	.....	.....	$130\frac{1}{4}$	$152\frac{1}{2}$	$178\frac{1}{2}$	$198\frac{1}{4}$	$223\frac{1}{2}$
18	.....	.....	.....	.....	137	$161\frac{1}{4}$	$185\frac{1}{4}$	209	$235\frac{1}{4}$
19	.....	.....	.....	.....	.....	$169\frac{1}{4}$	$195\frac{3}{4}$	$222\frac{1}{4}$	247
20	.....	.....	.....	.....	.....	178	$205\frac{1}{4}$	$233\frac{1}{3}$	259
21	.....	.....	.....	.....	.....	.....	214	$243\frac{1}{2}$	$273\frac{1}{4}$
22	.....	.....	.....	.....	.....	.....	$223\frac{1}{2}$	$244\frac{3}{4}$	$285\frac{1}{4}$
23	.....	.....	.....	.....	.....	.....	$233\frac{1}{2}$	$265\frac{1}{2}$	$298\frac{1}{4}$
24	.....	.....	.....	.....	.....	.....	$245\frac{1}{4}$	$277\frac{1}{2}$	$310\frac{1}{2}$

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF AMERICAN CAST-IRON.

	Breaking weight of a square inch bar.
Common pig-iron,	15,000
Good common castings,	20,000
Cast-iron, "	20,834
" "	19,200
" "	27,700
Gun-heads, specimen from,	24,000
" " "	39,500
Greenwood cast-iron,	21,300
" " (after third melting,)	45,970
Mean of American cast-iron,	31,829
Gun-metal, mean,	37,232
English Cast-Iron.	
Lowmoor,	14,076
Clyde, No. 1,	16,125
Clyde, No. 3,	23,468
Calder, No. 1,	13,735
Stirling, mean,	25,764
Mean of English,	19,484
Stirling, toughened iron,	28,000
Carron No. 2, cold-blast,	16,683
" " 2, hot-blast,	13,505
" " 3, cold-blast,	13,200
" " 3, hot-blast,	17,755
Davon, No. 3, hot-blast,	21,907
Buffery, No. 1, cold-blast,	17,466
" " 1, hot-blast,	13,437
Cold-Talon (North Wales), No. 2, cold-blast,	18,855
" " " 2, hot-blast,	16,676

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF AMERICAN WROUGHT-IRON.

	Breaking weight of a square inch bar.
From Salisbury, Conn.,	66,000
" Pittsfield, Mass.,	57,000
" Bellefonte, Pa.,	58,000
" Maramec, Mo.,	43,000
" " "	53,000
" Centre County, Pa.,	58,400
" Lancaster County, Pa.,	58,061
" Carp River, Lake Superior,	89,582
" Mountain, Mo., charcoal bloom,	90,000
American hammered,	53,900
Chain-iron,	43,000
Rivets,	53,300
Bolts,	52,250
Boiler-plates,	50,000
Average boiler-plates,	55,000
" joints, double-riveted,	35,000
" " single "	28,600
Chrome steel, highest strength,	198,910
" lowest "	163,760
" average "	180,000
Homogeneous metal,	105,732
" " 2d quality,	81,662
Bessemer steel,	148,324
" "	154,825
" "	157,881

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF ENGLISH WROUGHT-IRON.

	Breaking weight of a square inch bar.
English bar-iron,	56,000
Iron, mean of English,	53,900
" rivets,	65,000
Lowmoor iron,	56,100
Lowmoor iron plates,	57,881
Bowling plates,	53,488
Glasgow best boiler,	56,317
" ship plates,	53,870
Yorkshire plates,	57,724
Staffordshire plates,	43,821
Derbyshire plates,	48,563
Bessemer wrought-iron,	65,253
" " "	76,195
" " "	82,110
Russian " "	59,500
" " "	76,084
Swedish " "	58,084

TO POLISH BRASS.

Engineers will find the following receipt a very good one for polishing the brass work of their engines. Oxalic acid dissolved in rain- or cistern-water, in the proportion of half an ounce to a pint of water, if applied with a rag or piece of waste, will remove the tarnish from brass and render it bright; the surface should then be rubbed with an oily rag

and dried, and afterwards burnished with chalk, whiting, or rotten-stone. This is probably one of the quickest known methods for cleaning brass. A mixture of muriatic acid and alum, dissolved in water, imparts a golden color to brass articles that are steeped in it for a few seconds.

Owing to irregularities of surface, it often happens that considerable difficulty is encountered in putting a good polish on articles of brass or copper. If, however, they be immersed in a bath composed of aqua-fortis, 1 part; spirits of salt, 6 parts; and water, 2 parts, for a few minutes, if small, or about half an hour, if large, they will become covered with a kind of black mud, which, on removal by rinsing, displays a beautiful lustrous under-surface. Should the lustre be deemed insufficient, the immersion may be repeated, care always being taken to rinse thoroughly. All articles cleaned in this manner should be dried in hot, dry sawdust.

Another receipt for cleaning brass, nickel-plated ware, or German silver, is to dissolve one ounce of carbonate of ammonia in four ounces of water, after which it should be mixed with 16 ounces of Paris white. To apply it, moisten a sponge with water, dip it in the powder, rub quickly and lightly over the surface of the metal, after which it may be rubbed over with some of the dry powder on a soft cloth or piece of clean waste.

CEMENT FOR MAKING STEAM-JOINTS.

Take a quantity of pure red-lead, put it in an iron mortar, on a block or thick plate of iron. Put in a quantity of white-lead ground in oil; knead them together until you make a thick putty; then pound it; the more it is pounded, the softer it will become. Roll in red-lead and pound again; repeat the operation, adding red-lead, and pounding until the mass becomes a good stiff putty. In applying it to the flange or joint, it is well to put a thin grummet around the orifice of the pipe, to prevent the cement being forced inward to the pipe when the bolts are screwed up. When the flanges are not faced, make the above mass rather soft, and add cast-iron borings run through a fine sieve, when it will be found to resist either fire or water.

Another Cement. — Powdered litharge, 2 parts; very fine sand, 2 parts; slacked quick-lime, 1 part. Mix all together. So use; mix the proper quantity with boiled linseed-oil, and apply quickly. It gets hard very soon.

Another Cement. — White-lead ground in oil, 10 parts; black oxide of manganese, 3 parts; litharge, 1 part. Reduce to the proper consistency with boiled linseed-oil, and apply.

Another Cement. — Red-lead ground in oil, 6 parts; white-lead, 3 parts; oxide of manganese, 2 parts;

silicate of soda, 1 part; litharge, ½ part; all mixed and used as putty.

Another Cement. — Take 10 pounds of ground litharge, 4 pounds of ground Paris white, ½ pound of yellow ochre, and ½ ounce of hemp; cut into lengths of ½ inch; mix all together with boiled linseed-oil, to the consistency of a stiff putty. This cement resists fire, and will set in water.

Cement for Rust-Joints. — Cast-iron borings or turnings, 19 pounds; pulverized sal-ammoniac, 1 pound; flour of sulphur, ½ pound. Should be thoroughly mixed and passed through a tolerably fine sieve. Sufficient water should be added to wet the mixture through. It should be prepared some hours before being used. A small quantity of sludge from the trough of a grinding-stone will improve its quality.

Rust-joints, composed of sal-ammoniac, iron borings, flour of sulphur, and water, were formerly employed for all the permanent joints around engines; but they are fast going out of use and being replaced by faced joints.

Red-lead joints were also very generally used, but they are now obsolete, and justly so, not only for their dirty appearance, but also for the difficulty experienced in starting them, as it required, in most cases, the use of sledges and chisels, which incurred the danger of breaking the flanges.

All movable joints of the best description of land and marine engines are now faced on a lathe or

planer, and then rendered perfectly steam-, air-, and water-tight by filing and scraping, so that all that is necessary, when put together, is to oil their surfaces.

For smooth surfaces that can be conveniently calked, sheet copper, annealed by heating it to a cherry red, and then plunging it in cold water, makes a permanent joint.

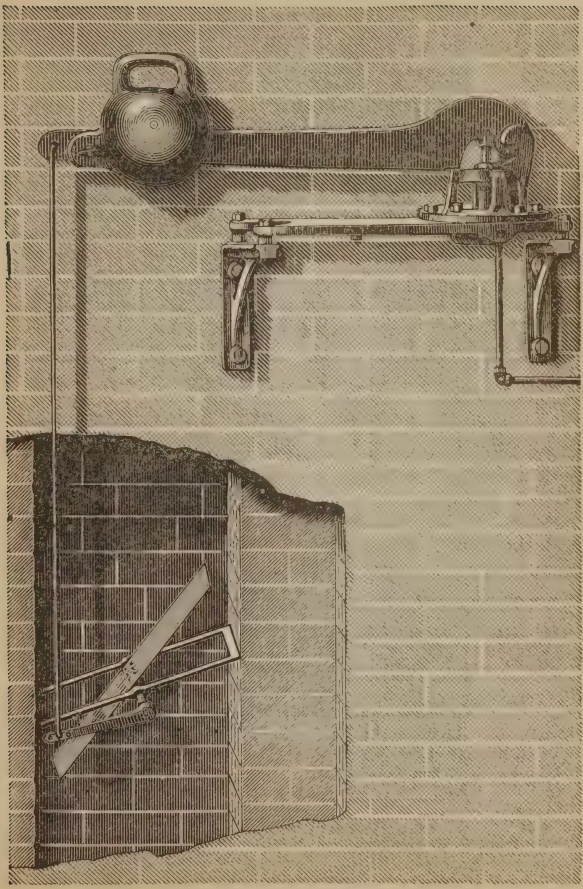
Lead wire makes a very cheap, clean, and permanent joint. Copper wire also makes a very good joint; but, when convenient, it is always best to plane or turn a groove in one of the surfaces to be brought in contact.

For uniform surfaces, gauze wire-cloth, coated on either side with white- or red-lead paint, makes a very durable joint, particularly where it is exposed to high temperatures.

For pumps of stand-pipes in the holds of vessels, canvas well saturated on both sides with white- or red-lead makes a very durable joint. Pasteboard painted on both sides with white- or red-lead paint is frequently used with good results.

STEAM- AND FIRE-REGULATORS.

The numerous devices which have been employed by engineers for maintaining a uniform pressure of steam in boilers, shows the importance of a contrivance for this purpose. As a consequence, many steam- and fire-regulators have been introduced to



AUTOMATIC STEAM-DAMPER.

the public; but most of them, from complexity or want of good workmanship, have failed to give satisfaction, and in many instances have proved to be of more injury than advantage.

The cut on page 339 shows an improved self-adjusting steam- and fire-regulator, simple and durable in its construction, and not liable to derangement or loss of sensitiveness from time or use; having perfect control of the damper, it will, when once set to any required pressure, maintain that pressure in the boiler so long as the required quantity of fuel is supplied.

These machines are in successful operation throughout the country; they maintain an even head of steam, with economy in the consumption of fuel, safety to the boilers, and general saving in wear and tear.

The following advantages are secured by these Regulators: Uniformity of pressure in the boiler. Economy of fuel averaging ten per cent. Freedom from explosions induced by excessive pressure. For these appliances, or any information concerning them, address

S. ROPER,
447 North Broad Street, Phila.

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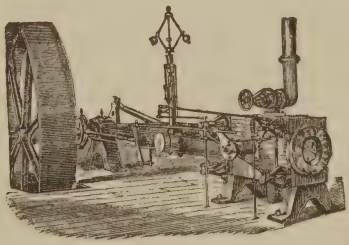

Of all the efforts of human ingenuity known, perhaps none has monopolized so large a share of inventive genius as the steam-engine. No other object in the entire range of human devices has so irresistibly arrogated to itself the devotion of scientific men as the production of an artificial movement from the vapor of boiling water.

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INTRODUCTION.

THE object of the writer in preparing these works has been to present to the practical engineer a set of books to which he can refer with confidence for information regarding every branch of his profession. Up to the date of the publication of these books, it was impossible to find a plain and practical treatise on the steam-engine. This arose, perhaps, from the fact that men who had attained proficiency in steam-engineering had no taste for devoting their limited leisure time to writing, and that those whose circumstances enabled them to do so, were precluded from a want of that practical knowledge which is only obtained by years of hard work and close observation. Many of the books heretofore written on the steam-engine are full of formulæ for calculating questions that may arise in the engine-room; but, as they are generally expressed in algebraical form, they are of little service to the majority of engineers; for, however useful such formulæ may be to the scientific, they can be of no practical value to men who do not fully understand them. It is also no less a fact, that nearly all writers on the steam-engine deal more with the past than the present. This is to be regretted, for, however interesting the bygone records of steam-engineering may be as a history, they cannot instruct the engineer of the present day in the principles and practice of his profession.

An experience of over thirty years, with all kinds of

engines and boilers, enables the writer to fully understand the kind of information most needed by men having charge of steam-engines of every description, and what they could comprehend and employ. With this object in view, he has carefully investigated all the details of stationary, locomotive, fire, and marine engines, taking up each subject singly, and excluding therefrom everything not directly connected with steam-engineering. Particular attention has been given to the latest improvements in all these classes of engines, and their proportioning according to the best modern practice, which will be of immense value to engineers, as nothing of the kind has heretofore been published. They also contain ample instructions for setting up, lining, reversing, and setting the valves of all classes of engines — subjects that have not received that attention from other writers on the steam-engine which their importance so justly merits. A certain portion of each book is devoted to an examination and discussion of the principles of Hydro- and Thermo-Dynamics, which include Air, Water, Heat, Combustion, Steam, Liquefaction, Dilatation of Gases, Molecular and Atomic Forces, Dynamic Equivalents, subjects with which the practical engineer should be fully conversant; as to ignore the principles of any subject is similar to building a structure without knowing the strength of the foundation; for it is only by a minute and careful analysis of the physical phenomena which convert heat into a motor force that the steam-engine has been brought to its present perfection.

S. R.

HAND-BOOK

OF

LAND AND MARINE ENGINES;

INCLUDING

THE MODELLING, CONSTRUCTION, RUNNING, AND MANAGEMENT OF LAND AND MARINE ENGINES AND BOILERS.

Fully Illustrated.

BY

STEPHEN ROPER, ENGINEER,

Author of

"Roper's Hand-Book of Land and Marine Engines," "Roper's Catechism of High-Pressure or Non-Condensing Steam-Engines," "Roper's Hand-Book of the Locomotive," "Roper's Hand-Book of Modern Steam Fire-Engines," "Roper's Handy-Book for Engineers," "Roper's Young Engineer's Own Book," "Roper's Use and Abuse of the Steam-Boiler," "Questions for Engineers," etc.

MARINE BEAM-ENGINE.

PHILADELPHIA:

EDWARD MEEKS.

Roper's Hand-book of Land and Marine Engines.

Opinions of the Press.

Iron Age, New York.

THE author of this hand-book says, in his preface, that his object in preparing it, "has been to present to the practical inquirer a book to which he can refer with confidence for information in regard to every branch of his profession."

Rules and directions expressed in algebraic formulæ are of little service to the majority of engineers, because they are not fully understood. The author, keeping this in mind, has avoided most of the points which render many of our hand-books of limited value to the practical man. He has had a long and extensive practical experience among the men for whom he writes, and understanding their wants, has produced a book which seems admirably adapted to those who have anything to do, in a practical way, with steam machinery. We have given the work a careful examination, and consider it one of the most satisfactory works of the kind we have ever seen. Mr. Roper thoroughly understands his subject, being entirely practical, and, at the same time, having a correct understanding of scientific principles. His chapters on the theory of steam engineering are so simple and practical that there is no mechanic in the country, however ignorant he may be of higher mathematics, who cannot learn all they are intended to teach. His practical directions for the management of engines are just such as we should expect from an experienced engineer who had spent all his

life in an engine-room, but who had learned the theory as well as the practice of his trade. They are plain and to the point, and the reader may accept them with an entire confidence. His descriptions of engines, pumps, and the appliances connected with engines, are exceedingly satisfactory, as are also his rules, which seem to be the best and simplest which could be formulated. The book has an abundance of tabular information, which seems to include all the tables that could be of any use. The engravings are good, and are just what is wanted to explain the text. In a word, the amount and kind of information contained in this work seems to be all that could be desired. The owner of a steam-engine cannot well do without it, and no one who runs an engine should be ignorant of any part of its contents.

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HAND-BOOK

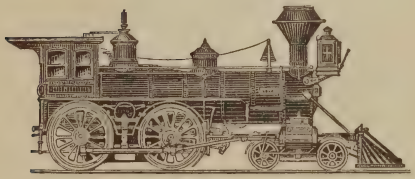
OF THE

LOCOMOTIVE;

INCLUDING THE

CONSTRUCTION, RUNNING, AND MANAGEMENT OF LOCOMOTIVE ENGINES AND BOILERS.

Fully Illustrated.



BY

STEPHEN ROPER, ENGINEER,

Author of

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PHILADELPHIA:

EDWARD MEEKS.

ROPER'S HAND-BOOK

OF

THE LOCOMOTIVE

OPINIONS OF THE PRESS.

Scientific American, New York.

The author of this work very truly believes that in a book, as in a clock, any complication of its machinery has a tendency to impair its usefulness and affect its reliability. Hence, in preparing a book which is intended to be a guide for the practical locomotive engineer, he avoids "mathematical problems and entangling formulæ," and offers a pocket volume, full of information, theoretical as well as practical, succinctly and clearly condensed. There are chapters on heat, combustion, water, air, gases and steam; others on the construction of the locomotive and of its various parts, entered into with considerable details; instructions for the care and management of boilers and engines, tables of strength of materials, and useful practical hints for the guidance of the engineer. In brief, the volume is, as its name indicates, a hand-book to which the locomotive mechanic can turn for information regarding almost every branch of his trade. It is neatly illustrated and bound in morocco, in convenient pocket-book form.

North American and United States Gazette, Phila.

Mr. Roper asserts as a preliminary qualification for his task, that he has had more than thirty years' experience with all

classes of steam-engines and boilers. The object of the work is to convey practical knowledge of all that appertains to the locomotive engine and boiler, in a practical manner. Stationary and marine engines are omitted, because other treatises furnish all that need be known of them. Mr. Roper seems to know *exactly* what the class for whom he writes require, and what they can comprehend and employ. His opinion, as expressed in his work, is the highest compliment ever paid to those in question, and to the railways of this country, by which this skill has been created and is sustained and promoted. The mechanical and dynamical equivalents of heat and its molecular force are treated in a clear and lucid manner. Chemical equivalents, the liquefaction and dilatation of gases, superheated steam, tractive and evaporative power, combustion, mensuration, incrustation, and similar subjects are discussed. The strictly mechanical information is fully and lucidly set forth, to an extent that would gain a degree in any of our schools. But beyond the rudiments, and beyond their combinations and applications, there is the pervading idea that the American engineer aims to know the effect by its cause—seeks philosophical knowledge as a part of his employment, and not only seeks, but, as a whole, has mastered so much that he deserves a standard in pure science very few have supposed. No higher compliment could be paid, and it could be paid nowhere else. The treatise apparently omits nothing, expresses clearly though compactly, furnishes tables, and is a fine tribute to the practical ability of the country. It contains suitable illustrations, and is appropriately prefaced with a portrait of M. W. Baldwin.

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HAND-BOOK

OF MODERN

STEAM FIRE-ENGINES,

INCLUDING THE

RUNNING, CARE AND MANAGEMENT OF STEAM FIRE-ENGINES AND FIRE-PUMPS.

BY

STEPHEN ROPER, ENGINEER,

AUTHOR OF "ROPER'S CATECHISM OF HIGH PRESSURE OR NON-CONDENSING STEAM ENGINES," "ROPER'S HAND-BOOK OF LOCOMOTIVES," "ROPER'S HAND-BOOK OF LAND AND MARINE ENGINES," ETC.

Second Edition, with Illustrations.

REVISED AND CORRECTED BY H. L. STELLWAGEN, M. E.

PHILADELPHIA:
EDWARD MEEKS,
1012 WALNUT STREET.
1889.

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A CATECHISM

OF

High-Pressure or Non-Condensing STEAM-ENGINES;

INCLUDING

THE MODELLING, CONSTRUCTING, RUNNING, AND MANAGEMENT OF STEAM-ENGINES AND STEAM-BOILERS.

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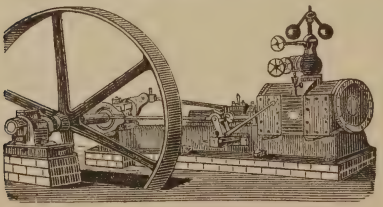

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ENGINEER'S HANDY-BOOK.

CONTAINING

A FULL EXPLANATION OF THE STEAM-ENGINE INDICATOR, AND ITS USE AND ADVANTAGES TO ENGINEERS AND STEAM USERS. WITH FORMULÆ FOR ESTIMATING THE POWER OF ALL CLASSES OF STEAM-ENGINES; ALSO, FACTS, FIGURES, QUESTIONS, AND TABLES FOR ENGINEERS WHO WISH TO QUALIFY THEMSELVES FOR THE UNITED STATES NAVY, THE REVENUE SERVICE, THE MERCANTILE MARINE, OR TO TAKE CHARGE OF THE BETTER CLASS OF STATIONARY STEAM-ENGINES.

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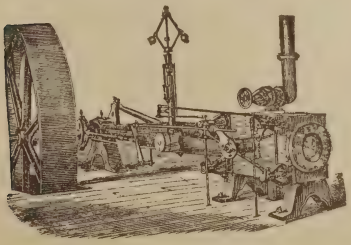

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The Manufacturer and Builder, New York.

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Millstone, Indianapolis, Ind.

"The Engineer's Handy-Book," by Stephen Roper, Engineer, is a practical treatise on the management of the steam-engine. The author says the book was "not written for the purpose of instructing engineers how to design or proportion steam-engines or boilers, but rather to inform them how to take care of and manage them intelligently." The declaration is carried out in the plainest and most systematic manner.

As a text-book for students in mechanical engineering, it will be found of great value. Its illustrations and tabulated matter are important features, and printed in excellent style

National Car-Builder, New York.

ROPER'S ENGINEER'S HANDY-BOOK.—This compact and comprehensive little volume contains a vast amount of information relative to the care and management of every class of steam-engines. It is profusely illustrated, and abounds in facts, figures, rules, tables, questions and answers, formulæ, etc., that are exceedingly valuable to engineers, and of easy reference by means of a copious and well-arranged index. The various subjects are discussed with brevity and clearness, and with a freedom from technicality which enables the reader to get at the pith of the matter without fishing it out from an ocean of words. A prominent feature of the book is a full explanation of the steam-engine indicator, and its use and advantages to engineers and others.

Leffel's Illustrated News, Springfield, Ohio.

ENGINEER'S HANDY-BOOK: By Stephen Roper, Engineer. —The author of the valuable series of hand-books which we have before referred to, has just issued the above-named work, which must find ready way into the hands of engineers and steam-users throughout the entire land. It contains a full explanation of the steam-engine indicator, its uses and advantages, with formulæ for estimating the power of all classes of steam-engines; also facts, figures, questions, and tables for engineers who wish to qualify themselves for the United States navy, the revenue service, the merchant marine, or the better class of stationary engines.

The American Engineer, Chicago, Ill.

THE ENGINEER'S HANDY-BOOK.—We are in receipt of the above work, which contains a description of the various forms of engines now in use, and supplies interesting and useful information as to the care, management, and remedy of defects of steam machinery and its appendages, with tables for calculating the power of engines.

American Machinist, New York.

ROPER'S ENGINEER'S HANDY-BOOK.—The subjects in this work have been treated in a brief and comprehensive way, therefore the reader is not required to read a number of chapters in order to acquire a little knowledge. The use of the indicator is treated in a plain, practical way, so that it may be readily understood. Abstruse formulas have been omitted and simple arithmetic used, thus avoiding the usual vexations among practical men who are uneducated in the higher mathematics. The author has in this book given the results of his own practical experience, which extends over a period of thirty years and upwards, and the work will doubtless be read with pleasure and profit by very many practical mechanics.

Engineering News, New York.

AN "ENGINEER'S HANDY-BOOK."—As a writer on subjects relating to steam and steam-engineering, Mr. Roper is now too well known to need any further introduction. In this, his latest contribution to steam-engineering literature, Mr. Roper has aimed to present to his brother engineers a "handy book" that will be to them what Trautwine's "Pocket-Book" is to civil engineers, and in doing this he has spared no labor in collecting and editing his materials. Some idea of the completeness of the work may be gathered from the statement of the publishers that it contains nearly 300 main subjects, 1316 paragraphs, 876 questions and answers, 52 suggestions and instructions, 105 rules, formulæ, and examples, 149 tables, 164 illustrations, 31 indicator diagrams, and 167 technical terms; over 3000 different subjects.

Boston Journal of Commerce.

MR. STEPHEN ROPER is well known as the author of several other handy-books that treat on steam, steam-boilers, and engines. This new work is, in our judgment, his best.

The Scientific American, New York.

A WELL made pocket-book of practical information for mechanical engineers, particularly those of limited education, and such as may wish to qualify themselves for service in the U. S. Navy or the mercantile marine. The more important engines in use are clearly described, and formulæ are given for estimating their power. Particular attention is paid to the steam-engine indicator, its use and advantages. The author has had much experience in this class of work, and writes clearly and plainly.

The Locomotive, Hartford, Conn.

ROPER'S ENGINEER'S HANDY-BOOK.—This last work of Mr. Roper is of special value to all who have to do with steam-boilers and engines, and it will be found a valuable shop companion for the mechanic. There are a great many facts collated that are not easily reached except through expensive books and libraries. These will be found of service to all classes of men, whether in trade or manufacturing. We commend it heartily, and believe it will have a large sale.

Forest, Forge, and Farm, Ilion, N. Y.

ENGINEER'S HANDY-BOOK.—We have received a book with the above title, by the well-known author and engineer, Stephen Roper, who has written a number of works on the subject of engineering. The eminent reputation of the author is a sufficient guarantee that the book is both interesting and useful. Mr. Roper has had an experience of over thirty-five years with all kinds of engines and boilers, and thoroughly understands locomotive, fire, marine, and stationary engines.

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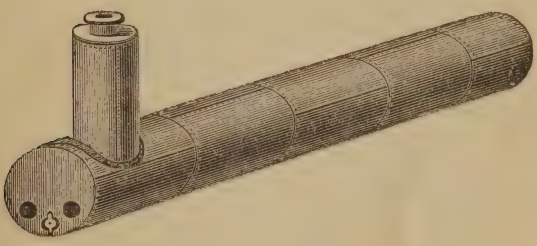
USE AND ABUSE

OF

THE STEAM-BOILER.



BY

STEPHEN ROPER, ENGINEER,

Author of

"Roper's Hand-Book of Land and Marine Engines," "Roper's Catechism of High-Pressure or Non-Condensing Steam-Engines," "Roper's Hand-Book of the Locomotive," "Roper's Hand-Book of Modern Steam Fire-Engines," "Roper's Handy-Book for Engineers," "Roper's Young Engineer's Own Book," "Roper's Use and Abuse of the Steam-Boiler," "Questions for Engineers," etc.

PHILADELPHIA:

EDWARD MEEKS.

59

Use and Abuse of the Steam-Boiler.

OPINIONS OF THE PRESS.

Engineering News, Chicago, Ill.

MR. ROPER is the author of several well-known hand-books relating to the steam-engine, and steam machinery in general. In this, his latest work, he states that his object is, "simply to show what the results of his thirty years' personal experience with all classes of boilers prove to be the safest and most durable materials for their manufacture; to show the absolute necessity of good workmanship in their construction, and to call the attention of owners, engineers, and firemen to the rules that limit their usefulness, safety, and longevity." As in all his other hand-books, the writer addresses himself to men of ordinary intelligence,—those found in charge of steam-engines and boilers,—and in consequence his book is written in the plainest and most intelligible language that can be chosen. We have not the time, nor possibly the necessary amount of practical knowledge of all the latest improvements in steam-boilers, to criticise closely and intelligently the contents of the book, but in connection with it we would call attention to the large number of boiler explosions, attended with great loss of life, that have recently occurred in this country and in England, and which, upon investigation, have been proven to be the results of ignorance and carelessness on the part of attendants; and we cannot but think that steam-users would find it greatly to their advantage if such plain handy-books as those of Mr. Roper's were placed in the hands of every attendant upon a steam-boiler or engine, and his attention called to the advantage of making himself familiar with its contents.

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